Analysis of the design process for low-energy housing

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Abstract

The present thesis presents an extensive description and analysis of the design process for a large-scale low-energy housing development (196 houses). The research is used to question the appropriateness of the RIBA *Plan of Work* for the delivery of low-energy housing and to give a unique insight into the motivations and interrelationships of project team members.

A mixed-methods approach was used to collect and analyse data. Qualitative data were collected from participant observation of over 40 design and construction meetings at the case-study development, as well as from documents distributed at these meetings. In addition, members of the core design team were interviewed. Data from these various sources were analysed using template, documentary and quantitative content analysis.

Decision analysis was used to investigate factors that affected the environmental impact of the houses. The impact of these decisions (and of particular decision makers) is discussed. The EcoHomes Standard had the largest influence on decisions, and many were renegotiated in construction to the detriment of the houses' environmental performance.

The research reveals that some project team members lacked understanding of the cost of sustainable construction. Several parties added up to 30% to actual construction costs. The experience of designing and constructing the low-energy houses increased all project team members' knowledge, and apparently changed how many operated and thought in their professional roles. Partnering and trust were very important in the project team, and good working relationships were essential. Cost (especially affordability of the houses) and sustainability were the strongest influences on decisions cited by project team members. However, compromises on the sustainability of the houses were observed because of the cost implications of some low-energy technologies, materials and building techniques. The RIBA *Plan of Work* did not hold the key to incorporating sustainability into the design process, as this was shown to be embedded in other issues, such as project team relations.

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Abbreviations and acronyms

The abbreviations and acronyms used in the present thesis are presented here for reference purposes. Each one is defined on its first use in a chapter.

ACE	Association for the Conservation of Energy
BedZED	Beddington Zero Energy Development
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Method
BSHF	Building and Social Housing Foundation
BSRIA	Building Services Research Information Association
BWEA	British Wind Energy Association
CABE	Commission for Architecture and the Built Environment
CASE	Cooperative Awards in Science and Engineering
CFL	compact fluorescent lamp
CGI	computer generated image
CIBSE	Chartered Institution of Building Services Engineers
CO_2	carbon dioxide
COI	Central Office for Information
DCLG	Department for Communities and Local Government
Defra	Department for Environment, Food and Rural Affairs
DPC	damp proof course
dph	dwellings per hectare
DETR	Department for the Environment, Transport and the Regions
DMU	De Montfort University
DTI	Department of Trade and Industry
DTLR	Department for Transport, Local Government and the Regions
EEASO	Energy Efficiency Advice Services for Oxfordshire
ECCP	European Climate Change Programme
EC	European Commission

EEBPH	Energy Efficiency Best Practice in Housing
EEPH	Energy Efficiency Partnership for Homes
EMDA	East Midlands Development Agency
EP	English Partnerships
EPBD	Energy Performance in Buildings Directive
EPSRC	Engineering and Physical Sciences Research Council
EST	Energy Saving Trust
EU	European Union
FSC	Forestry Stewardship Commission
GOEM	Government Office for the East Midlands
GPG	Good Practice Guide
GWP	global warming potential
HA	Housing Association
HIPs	Home Information Packs
IEA	International Energy Agency
IESD	Institute of Energy and Sustainable Development
INREB	Integration of New and Renewable Energy in Buildings
IPCC	Intergovernmental Panel on Climate Change
IPR	intellectual property rights
JCT	Joint Contracts Tribunal
JDA	Jackson Design Associates
K	Kelvin
kWh	kilowatt hours
LED	light emitting diode
m	metre
M&E	mechanical and electrical
MCDA	multi-criteria decision analysis
mg	milligrams
m/h	miles per hour
mtc	million tonnes of carbon

NCC	Nottinghamshire County Council
NEAA	Netherlands Environmental Assessment Agency
NGO	non-governmental organisation
NHBC	National House Building Council
NO_x	nitrogen oxide
NSDC	Newark and Sherwood District Council
ODP	ozone depletion potential
ODPM	Office of the Deputy Prime Minister
ONS	Office of National Statistics
Pa	pascal
PEP	Project Execution Plan
PFI	Private Finance Initiative
PPG	Planning Policy Guidance
PV	photovoltaic
PVC	plasticised polyvinyl chloride
RIBA	Royal Institute of British Architects
RMIT	Royal Melbourne Institute of Technology
SAP	Standard Assessment Procedure
SDRN	Sustainable Development Research Network
SEV	Sherwood Energy Village
SIP	structurally insulated panel
SPG	Supplementary Planning Guidance
SPTF	Sustainable Procurement Task Force
SUDS	sustainable urban drainage system
SUNH	Solar Urban New Housing
UK	United Kingdom
UN	United Nations
uPVC	unplasticised polyvinyl chloride
USA	United States of America
W	Watt

WWF	World Wide Fund for Nature

1. Introduction

In this chapter the aims and objectives of the research are stated and then climate change is introduced as the overarching context of the research. The chapter then introduces low-energy housing; one strategy to reduce the affects of climate change. The research collaboration integral to the research is then discussed.

1.1 Aims and objectives

The main aim of this research was to investigate how low-energy housing is delivered on a large-scale, private-sector housing development. This broad aim was realised through a number of more specific objectives:

1. To evaluate how the design process for the case-study development studied differs from conventional design process models.
2. To investigate how decisions made within the design process affect the economic, social and environmental characteristics of the houses in a large-scale, private-sector, low-energy housing development.
3. To evaluate the decisions made at the case-study development to maintain its commercial viability.
4. To investigate whether a new model of the design process for low-energy housing is necessary and, if so, how observations of the case-study design process can be combined with previous research findings to create such a model.
5. To use any new knowledge and understanding gained from this research to provide guidance to those involved in delivering low-energy housing to enable high environmental standards to be achieved.

1.2 Context

Climate change is part of the gradual alteration of the global environment over time, which is a natural process that has happened on Earth for billions of years. Climate change has, however, been dramatically accelerated by the release of carbon dioxide (CO_2) and other greenhouse gases into the atmosphere as a result of human activities (International Climate Change Taskforce, 2005). These activities include all actions that emit CO_2 or other greenhouse gases, the most significant being the burning of fossil fuels, such as natural gas, petroleum and coal. The UK, according to the former Department of Trade and Industry (DTI) (2003) produces two percent of global CO_2 emissions. The UK has a target of cutting its greenhouse gas emissions by 60% on 1990 levels before 2050 (Ibid) to try and control the detrimental effects caused by their release. This target is based on recommendations from the Royal Commission on Environmental Pollution (RCEP, 2000). The RCEP calculated that a 60% reduction would result in 65 million tonnes of carbon (mtc) being produced, which would be the UK's annual fair share of global emissions in 2050 (Ibid). This target does not, however, include increasing emissions from developing countries and the time delay between reductions and the stabilisation of the global climate. Taking account of these, the reduction target required in relation to buildings should be "80% in average carbon emissions per m^2 of building stock by the middle of the next century" (Lowe, 2000, p.164).

The UK is signed up to the legally binding Kyoto Protocol, part of the United Nations Framework Convention on Climate Change. This has set, as reported by the Department for Environment Food and Rural Affairs (Defra) (2002a), a short-term target for the UK of reducing emissions of six greenhouse gases by 12.5% on 1990 levels between 2008-12. The UK has also set itself an additional voluntary target of 20% over this period (Ibid). Similar Kyoto Protocol targets have been set for 160 countries and talks are now underway for the next stage, which it is hoped will include the United States, China and India. These three countries, according to United Nations (UN) statistics, accounted for over 44% of global CO_2 emissions in 2003 (UN, 2007). Since these figures were compiled, the Netherlands Environmental Assessment Agency (NEAA, 2007) has claimed that China has overtaken the United States as the highest producer of CO_2 emissions. China's contribution to global CO_2 emissions increased from 16% in 2003 (UN, 2007) to 44% in 2006 (NEAA, 2007).

The fourth report from the Intergovernmental Panel on Climate Change (IPCC, 2007) outlines the "key mitigation technologies and practices currently commercially available" as well as those "projected to be commercialised before 2030" (p.14). These are defined for seven sectors: energy supply, transport, buildings, industry, agriculture, forestry and waste. The report highlights that the buildings sector has the largest "economic potential for global mitigation" of climate change (Ibid, p.15). The report describes two main strategies to mitigate climate change, which are also highlighted in the UK government's *Energy White Paper: Our energy future – creating a low carbon economy* (DTI, 2003). These strategies are energy efficiency and renewable energy. Energy efficiency is used to lower the amount of energy used and renewable energy is used to reduce the impact of energy that is used.

Buildings are responsible for around 50% of all energy use in the UK, with substantial emissions reduction potential, especially in houses (RCEP, 2000). Horsley (2003) believes that new buildings "carry a more significant burden of responsibility since they must reflect society's increasing demand for more environmentally acceptable modes of living" (p.346). Energy use in buildings can be cut by several mechanisms, including: improving build quality to reduce energy demand; installing energy-efficient equipment; and installing local, clean and efficient sources of energy (Kelly, 2006). Energy efficiency offers the "largest, fastest, cheapest, and easiest reductions in carbon intensity available" (International Climate Change Taskforce, 2005), but cannot meet all reductions required. Renewable energy is proposed as the second main mechanism for tackling climate change, by replacing fossil fuels and therefore reducing greenhouse gas emissions. 'Renewable energy' is energy that is "derived from natural sources that are continuously at work in the earth's environment, and which are not depleted by being used", as defined by the Energy Efficiency Best Practice in Housing (EEBPH) (2003, p.3). Renewable energy and energy efficiency form two parts of sustainable development, which is development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (The World Commission on Environment and Development, 1987, p.8).

Energy used in houses is responsible for 28% of total UK energy consumption and CO_2 production in the UK (Defra, 2005). This figure is set to increase due to the rise in the number of new houses that are being built to accommodate decreasing household sizes (Boardman, Darby, Killip, Hinnells, Jardine, Palmer, Sinden, 2005) and increasing life expectancy, reported by the Office of National Statistics (ONS) (2006). Although only a small proportion of the UK building stock is newly built each year, if this is not built to the highest environmental standards then major retro-fitting will need to take place in the future and the opportunity for easy CO_2 reductions will have been wasted. The industry standard that houses are built to in the UK is determined by the current Building Regulations. These are put in place, according to the former Office of the Deputy Prime Minster (ODPM), to "secure the health and safety of building users, promote energy efficiency and make access easier for disabled people" (ODPM, 1999). *Part L1A: Conservation of fuel and power for new dwellings* (ODPM, 2006) applies to new-build housing. These regulations were updated in 2006 to include the *Energy Performance in Buildings Directive* (EPBD) (The European Parliament and the Council of the European Union, 2002), which, amongst other things, required new houses to have an energy performance certificate. These certificates were due to be introduced by the Department of Communities and Local Government (DCLG) through Home Information Packs (HIPs) (DCLG, 2007), which were delayed until August 2007, when they were phased in, due to lack of energy assessors. George Monbiot (2006) documented findings from a Building Research Establishment (BRE) report for the Energy Saving Trust (EST) and the Energy Efficiency Partnership for Homes (EEPH) (Grigg, 2004) that found, in 2004, that 43% of a sample of new houses checked for compliance with the statutory Building Regulations should have been failed, but in fact passed. This suggests that the potential CO_2 reductions from new houses based on Building Regulations are not being achieved.

Although there has been an increasing amount of research that states that people are concerned about the environment (e.g. Defra, 2002b), actions often do not reflect this stated concern. This phenomenon was supported in *Mind the Gap: why do people act environmentally and what are the barriers to pro-environmental behaviour* (Kollmuss and

Agyeman, 2002). This paper focused on the "gap between the possession of environmental knowledge and environmental awareness, and displaying pro-environmental behaviour" (p.239). There is, therefore, a need for houses to be designed to use as little energy as possible, and for energy demand to be minimised at the design stage rather than relying on energy-curtailment behaviours from occupiers.

Over the three years in which the present research was conducted, policy surrounding low-energy housing developed rapidly. When this research began EcoHomes was the most common environmental standard for low-energy houses in the UK (BRE, 2005) and formed part of the Building Research Establishment's Environmental Assessment Method (BREEAM). The EcoHomes standard provided an environmental rating for houses, which ranged from 'fail' to 'excellent'. The standard consisted of a comprehensive set of criteria in seven topic areas: energy; transport; pollution; materials; water; ecology; and health and wellbeing. These topics contained sub-topics with credits attached to each. These criteria were weighted according to their perceived impact. The EcoHomes standard was replaced by the *Code for Sustainable Homes* (DCLG, 2006b) in 2006, which was created by the Sustainable Building Task Group from recommendations in the government's *Energy White Paper* (DTI, 2003). The introduction of the code was announced during the later stages of the present research and was a direct replacement for EcoHomes to be administered by BRE in partnership with the DCLG. The overall aim of the code is to ensure that all new houses built in the UK by 2016 produce "zero net emissions of CO_2 from all energy use in the home" (DCLG, 2006b, p.7) (referred to as zero-carbon houses). The code consists of nine categories very similar to those of the EcoHomes standard: energy/CO_2; water; materials; surface water run-off; waste; pollution; health and wellbeing; management and ecology. Houses are assessed using a 'sustainability rating system' from level one (entry level) to level six (zero carbon). Criteria are tradable, but there are minimum standards set for energy/CO_2, water, materials, surface water run-off and waste (DCLG, 2006b). The Code for Sustainable Homes is to become compulsory, with the aim of building all new houses to the code's level three by 2010, level four by 2013 and level six by 2016, through updates of the Building Regulations (DCLG, 2006a).

Table 1.1 summarises the easily quantifiable criteria for achieving Building Regulations, EcoHomes excellent and four levels of the Code for Sustainable Homes. The table shows that the EcoHomes standard was a significant improvement on Building Regulations and includes many criteria that the Building Regulations did not. The table highlights the similarity between the EcoHomes excellent standard and level three of the Code for Sustainable Homes and shows the improvements on this through levels four to six of the code.

	Building Regulations			EcoHomes	Code for Sustainable Homes			
Criteria	1995	2002	2006	Excellent	3	4	5	6
U-values (W/m^2K) *approx								
Walls	0.45	0.35	0.28*	0.24*	0.22*	0.19*	0.14*	
Floors	0.35-0.45	0.25	0.20*	0.17*	0.16*	0.14*	0.10*	Zero
Roofs	0.20-0.25	0.16-0.25	0.15*	0.13*	0.13*	0.10*	0.075*	Carbon
Windows	3.0-3.3	2.0-2.2	1.8*	1.57*	1.57*	1.25	0.9*	
CO_2 emissions ($kg/m^2/yr$)			29*	≤ 25	23*	20*	14.5*	0
NO_x level (mg/kWh)				≤ 70	≤ 70	≤ 40	≤ 40	≤ 40
Boiler efficiency			≥ 86					
Renewable energy (% of demand)				10	15	15	15	100
Water consumption (litres/person/day) *approx				≤ 96*	≤ 105	≤ 105	≤ 80	≤ 80
Timber certification (% from Temperate forests)				75				
Materials responsibly sourced (%)					80	80	80	80
Density (% of dwellings at floor area:footprint ratio)				80 at 2.5:1	100 at 3:1	100 at 3:1	100 at 3:1	100 at 3:1
Sound insulation (Tests at dB level higher and lower than Building Regulations)				3	5	5	8	8
Private space (m^2/bedspace)				1.5	1.5	1.5	1.5	1.5
Cycle storage (% of dwellings)				95	100	100	100	100
Surface run-off reduction (%) *depending on area				50	50-100*	50-100*	50-100*	50-100*

Table 1.1: Quantifiable criteria for Building Regulations, EcoHomes excellent and levels three to six of the Code for Sustainable Homes

There are many other standards and codes that guide the development of new houses, including: the EST's *Best practice standard* (2007a); ZEDfactory's *ZEDstandards* (2004), created by Bill Dunster Architects who designed the Beddington Zero Energy Development (BedZED) (2004); and the *Passivhaus* Standard (Passivhaus Institut, 2006) created by the Passivhaus Institut in Germany.

Throughout the present thesis, houses that have better energy performance than conventional houses built to current Building Regulations will be referred to as either 'low-energy housing' or 'sustainable housing'. These two terms are used interchangeably in some of the literature reviewed for the present research. Low-energy housing is the default term used here, but if other literature has referred to houses as 'sustainable' this term will be used in relation to that particular work. Lovell (2005) addressed this issue and used a similarly broad definition for low-energy housing from a Department of Transport, Local Government and the Regions (DTLR) publication: "any dwelling which exceeds the current energy efficiency requirements of the UK building regulations" (Lovell, 2005, p.4).

1.3 Collaboration

This PhD research was conducted as part of the INREB (Integration of New and Renewable Energy in Buildings) Faraday Partnership, funded by the EPSRC (Engineering and Physical Sciences Research Council) as an industrial CASE (Cooperative Awards in Science and Engineering) studentship. This enabled the author of the present thesis to work in cooperation with an industrial sponsor, Sherwood Energy Village (SEV).

The extent to which an industrial sponsor is involved with the research varies depending on the sponsor, the university and the student. In this case, SEV was very much involved towards the beginning of the research and the author of the present thesis spent over 120 days at the organisation. Stan Crawford, Managing Director of SEV, was involved throughout the research and the Chief Executive, Carla Jamison was also involved towards the beginning. Conducting research with the industrial sponsor raised several confidentiality issues, which affected collection of data. The author of the present thesis had to be aware that many data were commercially sensitive, with vigilance being required to keep these data secure.

SEV is regenerating a 91 acre former colliery site of the same name, in Ollerton, North Nottinghamshire. SEV was formed in 1996, with the aim of "delivering practical regeneration that won't cost the earth – a nice place to live, work, learn and play" (SEV, 2006). SEV is an Industrial and Provident Society. Industrial and Provident Societies are private not-for-profit organisations which are community-based and owned and are actively involved in partnerships between the community, voluntary, private and public sectors (Social Enterprise Scotland, 2004). SEV was established by making investment opportunities available to members of the community and those with an interest in the principles and ideas behind the society. The investors will not a make profit from developments on the site. Each individual investor has one vote, regardless of how much money s/he has invested in the organisation. SEV is run by Stan Crawford, with all important decisions discussed by an elected board of directors.

The former colliery being developed by SEV once employed the majority of the local male population and was seen as "the centre of the community" (SEV, 2004). The colliery, shown in Figure 1.1, was in operation from 1926 until 1994 when the mine was closed. In 1994 a decision was made that the site was to be reused to create new jobs, diversify the local economy, provide housing and recreational facilities and, unlike the colliery, be non-polluting (Ibid). An extensive public consultation was undertaken in 1994-5 and a master plan for the site was agreed.

Figure 1.1: Sherwood Energy Village in 1994 before reclamation of the former colliery site took place (source: SEV)

In 1996 SEV registered as an Industrial and Provident Society. The site was purchased from British Coal in 1996 for £50,000, with an interest-free loan of £49,999 to be paid back when profit was recouped from developments on the site (SEV, 2004). In 2000, after much funding negotiation, English Partnerships (EP), through the East Midlands Development Agency (EMDA), provided a £2 million loan under a development agreement so that reclamation work could commence on the site (Ibid). As part of the reclamation work 100,000 tones of concrete and 1 million cubic metres of sand were reclaimed from the site and reused to give definition and separation to the site (Ibid). A sustainable urban drainage system (SUDS) was installed to divert rainwater from the conventional drainage system to allow it to infiltrate back into the ground, reducing the likelihood of flooding (Ibid). The regeneration of SEV is mixed-use, including industry, commerce, leisure, recreation and housing. The development is being undertaken in accordance with "environmental, ethical and sustainable principles" (Ibid) and a high environmental standard has been implemented via requirements in the 999-year lease applicable to each industrial and commercial plot (Ibid). Development on the site started in 2002 with several offices and light-industrial units. When the present thesis was submitted in September 2007, the site consisted of a variety of commercial buildings, shown in Figure 1.2, including SEV's head office in a flagship building for the site.

Figure 1.2: Sherwood Energy Village site, December 2005 (source: author of the present thesis's photo)

The housing development at SEV consists of 196 houses, including 12 house types designed by a local architectural practice. These range from two-bedroom flats to five-bedroom houses that will all be private-sector residences for sale on the mainstream housing market. The houses will be sold for competitive prices alongside other conventional developments in the area. The development for the houses was split into four phases. The construction of the first part of phase 1 (phase 1a) started in July 2006, and the entire development was due to be completed by 2010 (although phase 1a was not completed when the present thesis was submitted in September 2007). The development of phase 1a is the subject of this research. The houses are to be built to environmental standards in excess of Building Regulations, with EcoHomes excellent used for phase 1a.

Figure 1.3: Plan of case-study housing development (source: SEV)

The case-study houses were subject to various policies and regulations, including Building Regulations and the EcoHomes excellent standard. The local planning authority in which the houses were being developed, Newark and Sherwood District Council (NSDC), also had an impact on the houses. *The Newark and Sherwood Local Plan* (NSDC, 1999) described the District Council's policies and proposals for development in the area between 1991 and 2006. Policy E18 in the local plan referred to the SEV site and outlined conditions for development that included: high energy-efficiency standards; compliance with a comprehensive scheme for the site; not disadvantaging the existing amenities; satisfactory car parking; and appropriate landscaping. The *Planning Brief* for the SEV site was produced by SEV and NSDC and was adopted as Supplementary Planning Guidance (SPG) in November 2000. The SPG gave detailed guidance on how policies were to be applied to illustrate the benefits of sustainable development (NSDC and SEV, 2001).

In the NSDC *Local Plan* a lack of affordable housing was highlighted (NSDC, 1999) and NSDC conducted a *Housing Needs Survey* (NSDC, 2003) to inform affordable housing requirements for the area. This survey stated that the district council would negotiate with prospective developers to secure 30% affordable homes. To establish the affordable housing need in the Newark and Sherwood District, a supply and demand analysis of the housing stock was conducted in response to *Planning Policy Guidance (PPG) 3: Housing* (ODPM, 2005). This concluded that in the Ollerton and Boughton area, a 118 surplus of private stock and a 568 shortfall of affordable stock existed. The majority of this demand was for one- and two-bedroom flats in the social housing sector (David Couttie Associates Limited, 2003). SEV did not have to provide any affordable housing as "the case was presented to the local authority that as these properties are being built to the highest environmental standards, they will all be more affordable due to low running costs as a result of high design and construction standard" (SEV, 2005, p.5). This negotiation with NSDC resulted in the removal of the affordable housing provision on the SEV site, but additional planning conditions were applied. These are described in Chapter 5 (section 5.2.1 p.88) and included building to a zero-heating standard.

1.4 Thesis structure

This introductory chapter is followed by eight further chapters that address the objectives stated in section 1.1.

2. Literature Review. In this chapter a review of publications that address the issues underpinning this research are presented: low-energy housing and the design process.

3. Case-Study Data Sources. This chapter provides the data sources available at the case-study development, including: design team meetings; documents; project team members; and construction meetings.

4. Methodology. In this chapter a description of the methods used to undertake this research and an explanation of methodological choices is given.

5. A Design Process: incorporating the high environmental standard. In this chapter an investigation of where the high environmental standard needs to be addressed in relation to common elements of the design process to enable its incorporation is presented. A base-line design process is used to compare how the approach taken by the case-study development differs.

6. Design Decisions: exploring decisions that affect the environmental impact of houses. In this chapter qualitative analysis is used to investigate the decisions made within the design process that affect the environmental impact of the case-study houses. The decisions are analysed using decision analysis and are interpreted to examine how, why and when the decisions were made and what influence they had.

7. Professionals in the Design Process: their perspective. In this chapter a qualitative study of the project team members' attitudes towards the design process and their effect on the environmental standard achieved at the case study development, using semi-structured interviews, is reported.

8. Discussion. In this chapter integration of the findings presented in Chapters 5 to 7 with reference to other research conducted in this area, examined in Chapter 2, is undertaken. An evaluation of the houses on the case-study development is presented. Comparisons are made between the original concept for the houses and the environmental standard reached. The project team's behaviour during design team meetings is compared with their interview data. A new model of the design process for low-energy housing is presented, followed by overarching lessons and barriers from the case-study development.

9. Conclusion. In this chapter a summary of the conclusions of this research is provided. The limitations of the research are discussed, followed by questions for policy to address and further suggestions for enabling the development of low-energy and zero-carbon houses. Recommendations for future work are then presented.

A list of references and a set of appendices follows these chapters.

2. Literature Review

This chapter presents a review of literature that relates to the research objectives introduced in Chapter 1 (section 1.1, p.11). This review starts by examining literature that addressed low-energy housing and goes on to discuss literature that investigated the design process, as this is key to the delivery of low-energy housing. The review includes: design process models; decision making; and the project team. The aim of this review is to identify gaps in current knowledge and highlight objectives that could usefully and feasibly be met by the present research.

2.1 Low-energy housing

Low-energy housing has received increasing coverage in the UK and has continued to grow in popularity as the seriousness of climate change has been acknowledged by the government, local authorities, the private sector, the media and the public. In the last five to ten years there have been extensive developments in low-energy housing, reflected in the volume of material published on this subject. Books have addressed issues surrounding low-energy housing in general (Edwards and Turrent, 2000), focused on how to build an individual *Eco House* (Roaf, 2001; Vale and Vale, 2002) and presented a selection of low-energy houses worldwide (Stang and Hawthorne, 2005; Gauzin-Müller, 2006). The UK government produced several pamphlets, via the Energy Saving Trust (EST), that provided guidance about low-energy housing. One such pamphlet by Energy Efficiency Best Practice in Housing (EEBPH) provided information about *Building your own efficient house* (EEBPH, 2005). In the last few years there have also been several exhibitions that have addressed sustainable housing. These have included the Royal Institute of British Architect's (RIBA) *Future House London* (RIBA, 2004), *Prefabulous London: The A to Z of Modern City Homes* (The Building Centre Trust, 2006) and *Sustainable London* (Buro Happold and English Partnerships, 2007). International examples include *The Green House* at the National Building Museum in Washington (National Building Museum, 2005). There has also been coverage of low-energy housing at the popular *Grand Designs Live* (2006) exhibition and the *Ideal Home exhibition* (Ideal Home Exhibition, 2007). The following sections examine academic and non-academic literature on low-energy housing and address: individual houses; comparisons of houses; social housing; and private housing developments.

2.1.1 Individual houses

Literature that analysed individual low-energy houses either focused on one project in detail or compared several projects. Energy use and cost were the main areas researched in academic publications. Many examples achieved significant reductions in energy use for a relatively small additional build cost. The areas covered by publications that investigated one project in detail included: ecological impact of materials and construction techniques (O'Brien and Soebarto, 2000); evaluation of energy performance (Saitoh and Fujino, 2000); environmental assessments (Watson and Hyde, 2000); and the design process (Yoklic and Carneval, 2003). Areas covered by publications that investigated several projects included: use of passive solar systems (Goncalves, Oliverira, Patricio and Cabrito, 1998); energy evaluation (Hamada, Nakamura, Ochifji, Yokoyama and Nagano, 2003); solar low-energy housing (Nieminen, 2003; Thomsen, Poel and Schultz, 2005); life-cycle analysis (Fay, Vale and Vale, 2000); environmental impact of materials (Morel, Mesbah, Oggero and Walker 2001); and consumption data (Schnieders and Hermelink, 2006). These publications informed their specific areas, but were not directly relevant to the present research as all the studies addressed individual houses. The design process, financial issues and infrastructure for these houses was very different to those of a large-scale private-sector development.

2.1.2 Social housing

Social housing developments have been investigated in various academic publications. These focused on several areas, including: energy performance (Schnieders and Hermelink, 2006); user behaviour (Bullen, 2000; Petersdorff, Wouters and Wienser, 2000); evaluation of environmental standards (Lowe, 1986; Lowe, Bell and Roberts, 2003c) embodied energy (Thormark, 2006); and life-cycle costing (Smith and Whitelegg, 1997). These publications, like those concerned with individual houses reported projects carried out under very different financial arrangements to those in place at the case-study development.

2.1.3 Private-sector housing

There has been much less research on private-sector low-energy housing developments. Publications identified in this review focused on two areas: integration of renewable energy; and advice to developers. The integration of renewable energy technologies into housing was investigated by Spooner, Morphett, Watt, Grunwald and Zacharias (2000), where the integration of PV cells into the roofs of the Olympic Games athletes' village in Sydney was examined, with the aim of informing similar developments around the world. Advice given to developers was reviewed in Wilson, Walker, Santamouris and Jaure (1998) as part of the Thermie SUNH (Solar Urban New Housing) project, which involved housing developers in eight European countries. Although these studies did address large-scale low-energy housing, they did not focus on how it was actually delivered.

2.1.4 Summary

In summary, although there were a number of academic publications that dealt with low-energy housing, these tended to focus on individual and social housing projects, with very little on large-scale private-sector developments. This may be due to the fact that a greater number of social and individual housing projects are being developed and that their operators seem to be much more willing to provide access to data. There was a distinct lack of research that looked at the delivery of low-energy housing on a large-scale, or the design process to enable this. Publications that did refer to the design process included: Wilson et al. (1998), Morel, (2001), Fay et al. (2000), Yoklic & Carneval (2003), Lowe et al. (2003c) and Petersdorff et al. (2000). These publications did not, however, focus on the design process specifically and mostly related to individual houses or social housing developments, both of which have very different financing and delivery structures from those at the case-study development. The present thesis focuses on the analysis of the design process for a large-scale, private-sector, low-energy housing development. The following sections of this chapter examine academic and non-academic literature that has addressed different aspects of the design process.

2.2 The design process

Literature that addressed the building design process or elements of that process were identified from academic and non-academic sources. It covered a wide range of subjects that were grouped into eight areas. Four of these areas, about which less research had been published, are discussed in this section. The remaining four are discussed in the proceeding sections. The four areas to be discussed in this section are: the design brief; energy performance standards; integrated design process; and sustainable procurement.

2.2.1 Design brief

The creation of the design brief, one of the first stages in the design process, was investigated by Watson, Cheshire and Hyde (2000) and Watson (2004). In Watson et al. (2000) the hypothesis was stated as "if the environmental criteria are set when the brief is developed there is a better chance that they will be included during the design development stages" (Ibid p.791). The method was an action/reflection model of the design process for two case-study houses, which was not described in detail. The research concluded that, as predicted, when environmental criteria were included in the design brief the case-study houses had a lower environmental impact. This research was continued in Watson (2004), where the model was developed and tested with empirical data from several case-studies, to enable the certainty of the model to be better established. The study found that "for design solutions to achieve the environmental performance level desired by clients, goals must be put in place as early as possible in the design process" (Ibid p.13). This research concentrated on the development of a complex model that used equations to represent different elements of the design process. This could not be easily translated into practical guidance to deliver low-energy projects and only covered one of the initial stages of the design process. The present thesis investigates the entire design process as opposed to just the design brief. A model is also created in the present thesis, which is explicitly designed in the form of practical guidance for those developing low-energy housing.

2.2.2 Energy performance standards

Energy performance standards for new houses were investigated by researchers at Leeds Metropolitan University over an extended period of time. The first research report (Lowe et al., 2003c) aimed to "explore the implications of an enhanced energy performance standard for new housing for the design, construction and performance of timber framed dwellings" (Ibid, p.v). Due to time constraints only the design phase was investigated at the case-study of 18 low-energy affordable houses in St Nicholas Court, York. Action research was employed and data were collected from an array of sources, including design team meetings, interviews, informal meetings and workshops. A design solution was presented for the houses and a list of recommendations for future projects was presented. These covered: performance; cost effectiveness; construction technology; design team and the design process; and training and professional development. This research report was published in two papers for Structural Survey (Lowe, Bell and Roberts, 2003a; 2003b). In later work by the same research team (Roberts, Lowe and Bell, 2005), another case-study development was used to evaluate the implementation of the same standard and support the review of the Building Regulations. Action research was employed again and the dwellings were masonry as opposed to timber to reflect the majority of mainstream housing developments. The study investigated 700 houses to be built by mainstream private housing developers. The process was tracked into construction and occupation. Air pressure testing of dwellings showed that all those tested were below the target of 5 m/h at 50Pa. The research also found that the "two-way training programme" (Ibid, p.4494) used on site helped to "improve performance, cost and buildability" (Ibid). These studies focused on elements of the houses rather than the actual process to deliver them, which the present thesis addresses. They did, however, use similar methods of data collection and the report is very comprehensive, describing in detail the methods used.

2.2.3 Integrated design process

The integrated design process, which is made up of a cross-disciplinary project team working towards the production of buildings that meet social, economic and environmental aims (Reed and Gordon, 2000), was investigated in three publications. Reed and Gordon

(Ibid) assessed integrated design process initiatives in Canada, Finland and the United States and identified further research and practical needs. Approaches to integrating low-energy strategies into the conventional design process were presented and a number of recommendations listed: selecting the appropriate consultants; considering ecological issues; close involvement with the client, community and regional stakeholders; performance based agreements; contractor training; and proper commissioning. The paper suggested that further research was needed in this area as "the concept of integrated thinking will change the building industry" (Ibid, p.337). Yoklic and Carneval (2003) investigated the "primary infrastructure concerns to facilitate conventional habitation of a remote desert site" (p.877) using an integrated design process. Using this integrated approach the house was able to be self-sufficient from non-fossil fuel sources of energy and supply itself with a sustainable water supply. The integrated design methodology meant that "traditional site and climate limitations had to be viewed as assets to be used to reduce or eliminate the need for resources" (Ibid, p.877). These included: using the roof as a rainfall collector and support for photovoltaic cells (PV); and using the conventional interior of the building for natural ventilation and outdoor living (courtyard). These publications investigated the integrated design processes, which the case-study development for the present research also used. The studies, however, focused on the elements of the building rather than the design process itself and the only domestic example was investigated by Yoklic and Carneval (2003), which was for an individual house rather than a development. The methods used in the study by Reed and Gordon (2000) were not described in any detail.

Torcellini, Pless, Griffith and Judkoff (2005) aimed to "refine and test the integrated building design process" (Ibid, p.xi) to reduce the energy consumption of the National Renewable Energy Laboratory's Thermal Test Facility. This was accomplished by using computer simulations, which achieved a 63% reduction in cost to heat, ventilate, cool and light the building, compared to a base-case building. The research provided recommendations on how to use an integrated design process, which included: "assemble a project team committed to a low-energy building" (Ibid, p.102); "set quantifiable energy performance goals" (Ibid, p.103); "use energy models to guide design decisions" (Ibid, p.104); and "write clear and complete specifications for unique energy features" (Ibid, p.105). The same research team investigated how an integrated design process was used at the Zion National Park Visitor Centre, Utah, to reduce energy use by 70% compared to a base-case building (Long, Torcellini, Pless and Judkoff, 2006). The building was monitored for a two-year period, which showed a "67% energy cost saving" (Ibid, p.1). Lessons learnt were also presented for future projects of a similar type and included: setting energy performance goals; using the building design to reduce energy use; encouraging team work; using energy models to predict performance; and review of the process used. These two publications focused on energy performance in large-scale buildings and did not provide any information about the methods used.

2.2.4 Sustainable procurement

Sustainable procurement is the process of sourcing materials and services in a sustainable manner (Ellinor, 2007). The issue of sustainable procurement has become more prominent since the government's Sustainable Procurement Task Force (SPTF), set up in 2005, was charged with examining how to spend the public sector's £150 billion budget on goods and services in a sustainable way (Ibid). The government was inspired to lead on this issue as a report by the Sustainable Action Group (2000) found that industry expected government to do so. In 2006, the SPTF created a report entitled *Sustainable Procurement National Action Plan: Procuring the Future* (Defra, 2006), which suggested six key recommendations: lead by example; set clear priorities; raise the bar; build capacity; remove barriers; and capture opportunities. These were then underpinned by three 'building blocks': flexible framework; prioritisation of spend; and toolkits.

Action Energy, now part of the Carbon Trust (an independent company funded by government) published two Good Practice Guides (GPG) that looked at procurement: *Procuring smart, energy efficient office buildings* (Action Energy, 2004a) and *Achieving smart, energy efficient office buildings through the supply change* (Action Energy, 2004b). The first of these outlined 'strategic golden rules', giving detailed advice about procurement for various building elements, some of which were relevant to the present research. These included: building form and function; building fabric; lighting; space heating and hot water controls; and other sustainability issues (Action Energy, 2004a). The second went through some phases of the design process and focused on the supply chain, giving advice for each aspect related to procurement (Action Energy, 2004b). A table of issues related to procurement that might arise at each stage of the design process was presented. This included issues related to the present research, such as: setting energy performance objectives; budgeting for energy efficiency; agreement between architects and engineers; value engineering; competence and commitment of contractors; construction cost issues; and decision-making authority (Ibid). These non-academic publications do not give any details of the methods used to produce their findings and were specifically focused on non-domestic buildings. However, some of the findings, as described, were of relevance to the present research.

2.2.5 Summary

The literature reviewed in this section related to the building design process or elements of the process. Half of the literature reviewed focused on non-domestic buildings, the design of which is approached in a very different way to dwellings, due to financing issues and scale. Several of these publications used computer simulations to test and refine building designs. This is not as relevant to housing design because of the scale of the buildings and the cost associated with this type of technique. Most of the publications used case studies as their main source of data collection. These ranged from individual houses to groups of non-domestic buildings. Many of the projects used interviews, graphical information and design team meetings, which are used in the present research. Three of the publications were especially relevant to this research as they investigated the design process of case-study housing developments. Watson (2004) developed a theoretical model of the design process for low-energy housing, but this was very complex and would be difficult to translate into practical guidance, especially as it only focused on the design brief. Lowe et al. (2003a, 2003b and 2003c) investigated how an environmental standard could be incorporated into the design of a small-scale timber social housing development. In a continuation of that research, Roberts et al. (2005) investigated how an environmental standard can be incorporated into the design of a masonry large-scale private-sector housing development, using action research. The low-energy elements of these projects were led by the researchers and Roberts et al. (Ibid) focused on testing and monitoring the building after construction and occupation, rather than the design process. The present thesis investigates the design process of a low-energy, private-sector housing development to collect data that could form practical guidance for those involved in the development of low-energy housing projects. The present thesis addresses all issues outlined in this section for the majority of the design process for low-energy housing. As such, its scope is wider than that of any of the publications reviewed in this section.

2.3 Design process models

Literature that addressed models of the design process were identified from academic and non-academic sources. In this literature many model types were discussed. These were grouped into three categories: purely theoretical; linear; and integrated. These are discussed in the following sections.

2.3.1 Purely theoretical models

Purely theoretical models of the design process, based solely on theory, were presented in four publications: Hamel (1994); Lawson (2004); Pagani (1999); and Golland and Blake (2004). These models were all based around four phases of the design process: briefing, analysis, synthesis and evaluation. These publications have developed this four-stage model, one version of which is presented in Figure 2.1. These models were not directly relevant to the present research as they can not be interpreted into 'real-life' design processes and do not address the issue of the incorporation of high environmental standards. Figure 2.1 shows the complexity of one of the models, which is very difficult to relate to the 'real' design process as observed at the case-study development. These models have, however, influenced other models that are described in this section.

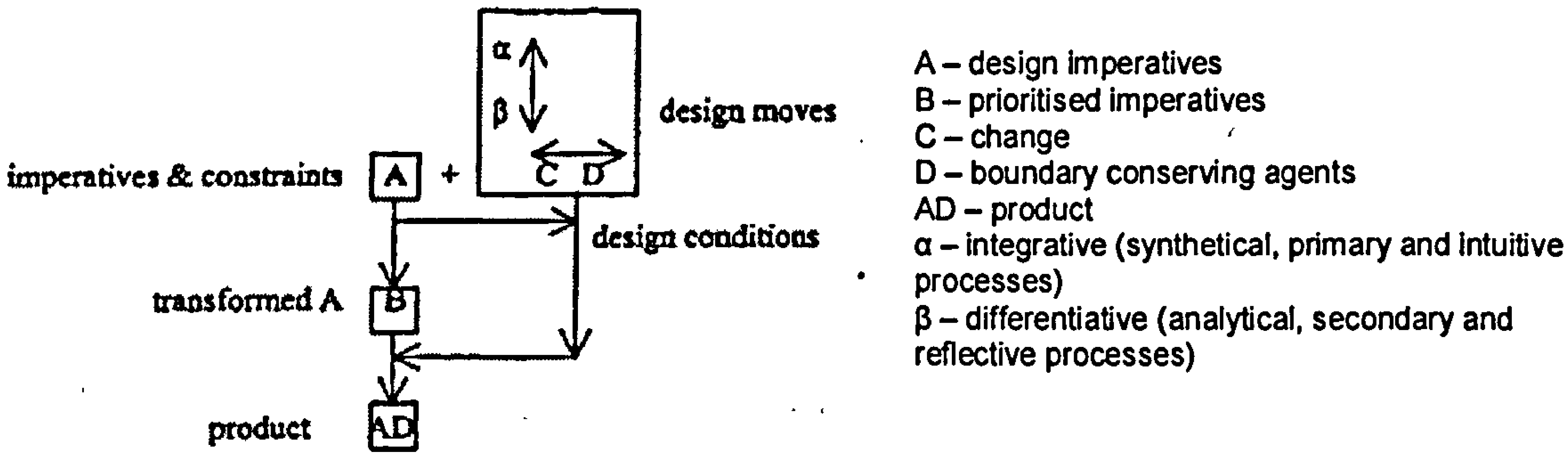

Figure 2.1: Pagani's design process model (Pagani, 1999, p.78)

2.3.2 Linear models

Linear models, which flow in lines, were presented in several publications. The original Royal Institute of British Architects (RIBA) model was created as a guide to the design process (RIBA, 1965) and was influenced by theoretical models, similar to those discussed in the previous sub-section. This model is used by members of the RIBA and has been updated a number of times since the original version. The most recent model (RIBA, 1998) included 11 linear stages: appraisal; strategic brief; outline proposals; detailed proposals; final proposals; production information; tender documents; tender action; mobilisation; construction to practical completion; and after practical completion. This model was used as the base-line design process for comparison with the case-study design process and is described in detail in Chapter 5 (section 5.1, p.85).

Macmillan, Steele, Kirby, Spence and Austin (2002) presented a model concentrating on the concept stage of a design process. This was developed by comparing "current process maps, and through interviews and case study analyses" (Ibid, p.174) over a two year period. The model had 12 activities in five stages that outlined the steps needed to undertake conceptual design. The model focused on one stage of the design process, whereas the present thesis investigated the majority of the design process and focused on a low-energy product.

2.3.3 Integrated models

Two publications presented integrated models of the design process, which combine stages to create a circular model. Pearl (2004) presented an integrated design process where "the client takes a more active role than usual, the architect becomes a team leader rather than the sole form-giver, and the structural, mechanical and electrical engineers take on active roles at early design stages" (Ibid, p.32). The model, shown in Figure 2.2, has 14 phases that are linked in a circle as well as having links to each other via feedback loops and into the central core of the model that states the performance targets for the project. The model was tested on architecture students in Canada as well as real projects, including the L'Oeuf charrette where the model was tested with very good results in terms of reduction of energy use (70%). In this test, knowledge and understanding by the project team were seen as key to the successful implementation of the model. The methodology for developing this model was not explained, however, it is very relevant to the present research as it is a model of a design process for low-energy projects that is applicable to 'real-life' design processes. The model was, however, not presented clearly and even in the original publication it was difficult to distinguish what all the stages were, so it was recreated by deciphering the text on the diagram magnified 500%. The performance targets being at the centre of the model was key, as this enabled them to influence all stages of the design process.

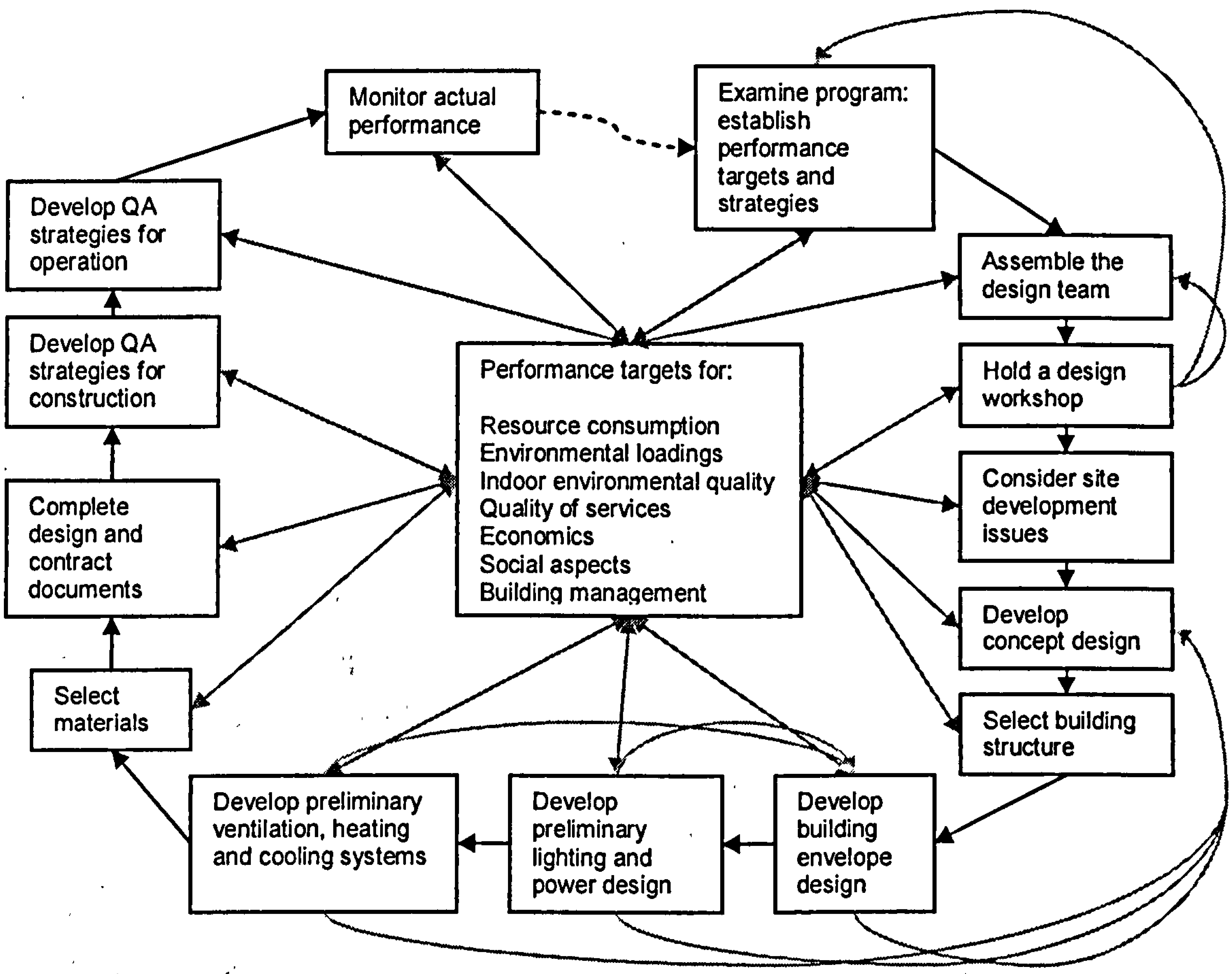

Figure 2.2: Recreation of Pearl's integrated design process model

Brand (2006) created a model that integrated a sustainability matrix into a sustainable building cycle as part of a study that evaluated 51 tools used to establish the sustainability of buildings in the Netherlands. The model, shown in Figure 2.3, has eight phases, each of which feeds into the next. This model was created after evaluation of existing tools found that there were no tools that focused on the execution stage of the design process. The study concluded that although there was "an abundance of tools to support sustainable development... their effect on real sustainability seems to be fragmented" and that "an integral life-cycle approach, and tools that fit in this cycle" (Ibid, p.5) were needed. The model did not seem to be directly applicable to 'real-life' projects as it did not give adequate detail and did not have enough additional guidance to be used to enable high environmental standards to be incorporated into the design process for low-energy buildings.

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development, the project team were not using MCDA and the decisions were made without interference from the author of the present thesis.

2.4.2 Life-cycle analysis

Life-cycle analysis is the quantitative analysis of the environmental impact of a product over its lifetime and was used in several publications reviewed to assist in the decision-making process. Fay et al. (2000) investigated the impact design decisions had on life-cycle energy by comparing two case-study houses, one with low embodied energy and the other high embodied energy but very low operational energy. Heating and cooling requirements for each house were predicted by using a computer simulation programme. The results from the programme predicted that the life-cycle energy for the house with higher embodied energy would be lower than that of the house with lower embodied energy after just 25 years. The recommendation from the study was that reducing operational energy was very important, even if it increases the embodied energy, as over the life cycle of the building it would use less energy. The study concluded that "design decisions critically influence building life-cycle energy requirements and thereby the quantities of greenhouse gas emissions" (Ibid, p.169).

Bartlett and Howard (2000) investigated the whole life cycle and environmental impact of Private Finance Initiative (PFI) buildings with the aim of encouraging stakeholders to make 'sustainable decisions'. PFI projects include: hospitals, infrastructure, property, defence, education and prisons, which were outlined in general terms in this paper. Empirical data from two unspecified case-study buildings were investigated in depth. The first followed the design process of an air conditioning system with a focus on whole life costs to identify the design changes that related to capital cost and predicted energy consumption. The second investigated the whole life costing options for an internal wall over 60 years. These case studies demonstrated that "cost consultants seriously overestimate the capital costs of energy efficient measures and seriously underestimate the potential for cost savings and value added as trade-offs" (Ibid, p.324). The cost consultants were seen to overestimate build costs by between five percent and 15%. The study concluded that the consideration of life-cycle costs can achieve cost-effective sustainable development (Ibid).

Horsley, France and Quatermass (2001) presented a decision support tool for project teams on energy performance issues, focusing specifically on the life-cycle costs of PFI buildings. They stated that "energy performance of buildings is not a straightforward issue, and depends on the close integration of client, designer, contractor and operator in order for good performance to be achieved" (Ibid, p.355). The study found that if a building's environmental impact was considered in the concept design stage then there was a huge potential for energy savings. These publications investigated what can be done to reduce the embodied energy of buildings. This issue was addressed in the present thesis, but it was not possible to undertake a life-cycle analysis of the case-study houses as the necessary data were not available.

2.4.3 Other decision frameworks

Literature that covered the two areas of decision-making identified above were reviewed, but there were some publications that did not fit into these categories and presented other decision frameworks. Mackinder and Marvin (1982) investigated the 'routes' taken to make design decisions in a range of domestic and non-domestic buildings. Interviews and diaries were used as the main data collection instruments from architects in six case studies. The study presented influences on design decisions, which included: written material; experience; and outside technical help. The study also divided design decision making into three main areas: programme activities; design activities; and design decisions and reasons. These areas were addressed within the present thesis, but the focus was on the design process with design decisions being only a part of this.

Andreu and Oreszczyn (2004) investigated the role of feedback to improve consideration of environmental issues when making decisions. Three case studies, two speculative office buildings and a glass museum, were used to illustrate the decisions made during their design and construction. These decisions were fed back to architects involved in similar projects to inform the design and construction, in relation to environmental considerations. The architects were then asked to assess the relevance of the feedback, with the majority stating that this type of feedback was necessary. The study concluded that architects should record "the decisions they make clearly and a willingness to know the consequences of such decisions in practice" (Ibid, p.326). In the present thesis the decisions made by the project team were analysed and will be fed back to them through this thesis, which is a recommendation of Andreu and Oreszczyn (2004).

Ofori and Kien (2004) studied the level of environmental awareness of architects in Singapore when making decisions about materials. This was done using questionnaires, finding that although architects knew about the environmental impacts of building materials they were not incorporating this knowledge into their designs. The study presented "key policy directions for government, professional bodies, educators and clients... to enable Singapore architects to apply their knowledge of environmental issues in their design decisions" (Ibid, p.27). The research suggested ways of encouraging architects to use their knowledge to design more sustainable buildings. The issue of knowledge was addressed in the present thesis, but with reference to all decision makers, not just architects.

Watson (2004) examined the need to make decisions that affect the environmental impact of buildings as early as possible in the design process. Watson (2004) stated that the design brief is key to this aim as "if the problem is not set out in the design brief, then it is unlikely to form part of the design solution" (Ibid, p.1). The research concluded that "recording the issues considered, goals set and decisions made benefits not only the project for which the brief is being developed, but future projects" (Ibid, p.13) due to the complex nature of environmental issues. The role of the design brief was explored in the present thesis. This was undertaken along with the analysis of the entire design process, not just a small part, which Watson (2004) focused on.

2.4.4 Summary

The literature reviewed in this section addressed decisions made by the project team. More than half of the publications mentioned used multi-criteria decision analysis. This can, however, only be used when the researcher can implement this technique when decisions are being made or if it is already being used. Several other publications used life-cycle analysis to aid decision making in the design process, which again, could only be used if the researcher could gather the information necessary or if it was being used already. Life-cycle analysis could be undertaken as part of multi-criteria decision analysis, but this was not explored by any of the publications. Architects' decision making was the focus of three publications, which did not consider the role of any other project members in this process. Case studies were used in much of the research reviewed, with data coming from two main sources; professionals involved in the design process and buildings constructed using the design process. Interviews, diaries and questionnaires were also used in some studies. There appeared to be little research that investigated specific decisions related to the environmental impact of buildings, which the present thesis addresses. The present thesis examines the influences that all project team members had on the decisions being made in a real-life design process that the author of the present thesis had no control over.

2.5 The project team

Literature that has discussed the project team involved in the building design process were identified from academic and non-academic sources. This literature addressed a wide range of elements related to the project team, which are divided into four categories: responsibility, knowledge, communication, and partnering.

2.5.1 Responsibility

Riley, Pexton and Drilling (2003) investigated the role of the contractor in the US construction industry in delivering sustainable buildings, including their power over the procurement process. Twenty case studies of 'green' buildings in the US and 40 interviews with professionals working in the construction industry were analysed to assess this influence. The study concluded that contractors have "both the potential and the responsibility to enhance green building project teams" (Ibid, p.69) and that this potential can only be realised if they are involved in the design process during the early design stages. The study reported that "efforts to become more sustainable also create incentives to adopt logical and much needed improvements to the traditional sequential design and construction process" (Ibid, p.66), stating that sustainable building practices should be referred to as 'sensible' building practices to encourage their incorporation into the mainstream.

2.5.2 Knowledge

The knowledge of project team members was addressed in three of the publications reviewed: Sandahl, Shankle and Rigler (1994), Fortune and Welham (1995) and Lowe et al. (2003c). Sandahl et al. (1994) surveyed architects and designers to investigate their knowledge of energy standards and the influence that these have on the design process. The research concluded that all parties can influence the energy use of a building and that this is most effective towards the beginning of the design process. A survey of project team professionals was undertaken in Fortune and Welhame (1995) to investigate their awareness of "environmental legislation and initiatives" (Ibid, p.511). The study found that the environmental awareness of these parties was at "background level only" (Ibid, p.519) and that their learning processes could be improved. Lowe et al. (2003c) used interviews with the core project team to explore their knowledge and understanding of environmental issues. The project team members were grouped into four categories according to their existing knowledge: "good grasp of the general principles of energy efficiency housing" (Ibid, p.102); "very little knowledge of either detail or the general principles… but who had sound technical knowledge of building construction and current regulations relating to energy efficiency requirements" (Ibid, p.103); "very detailed product knowledge and a broad understanding of its potential application" (Ibid, p.103); and "little technical knowledge but had a broad understanding of the performance requirements and some of the principles behind achieving them" (Ibid, p.103). All of these groups, when interviewed, stated that their knowledge base had improved. As well as investigating knowledge and understanding of the project team, Lowe et al. (Ibid) also explored the change in the general views and attitudes towards the project. The research found that "in general, attitudes simply became more positive and beliefs about both the importance and feasibility of achieving higher energy and environmental standards were strengthened" (Ibid, p.100).

These publications addressed project team members' knowledge of environmental strategies and have shown that through working on low-energy projects, knowledge increased. In the present thesis, knowledge of environmental strategies and standards is investigated and lessons learnt reported and communicated back to the project team members. As in Lowe et al. (2003c), the project team at the case-study development had a wide range of knowledge and experience of low-energy projects, which affected the amount that individual team members learnt from working on the case-study development.

2.5.3 Communication

Communication between project team members was discussed in Wallace (1987) and Gorse, Emmitt, Lowis and Howarth (2001). Wallace (1987) investigated the communication pattern of architects during the decision-making process. The study used one longitudinal and 14 cross sectional case-studies as well as interviews and content analysis of design team meetings. The findings showed that architects' involvement in decision-making were much less overt in the middle stages of the design process and that cost became an increasingly important influence throughout, often at the expense of aesthetics.

Gorse et al. (2001) examined the social interactions of the project team at four case-study building projects. Observation of at least three design team meetings for each project was undertaken using interaction process analysis, a form of content analysis used to interpret "social interactions in small face-to-face groups" (Ibid, p.763). This analysis revealed that the architect and the contractor were key to the design and management of the building projects studied, as they were heavily involved in decision-making. The research suggested that further investigation was necessary to identify a base-case of interactions between project team members and that these could be classified as successful or unsuccessful interpersonal relationships, depending on the outcome of the development.

These two publications focused on the interactions between project team members, which was investigated to some extent in the present thesis. This was not, however, the focus of the study as this type of analysis is very time consuming and the present research was more concerned with the overall design process for delivering low-energy housing.

2.5.4 Partnering

Partnering is "an agreed method of working together as an integrated and co-ordinated team to achieve common objectives and shared benefits" (Constructing Excellence, 2006). Weingardt (1996) and Lowe et al. (2003c) investigated the role of partnering between project team members in the design process. Weingardt (1996) investigated the role of partnering between architects and consulting engineers. Case studies were used to provide evidence of successful partnering. The authors concluded that partnering enabled budgets to be achieved and better decisions made. They also suggested that partnering should be started at the beginning of the project and everyone should be invited to be involved in the process.

Lowe et al. (2003c) explored partnering through interview data and concluded that "the partnering approach provided the team with the necessary flexibility to deal with uncertainty and to engage in a level of communication commensurate with the degree of learning required to produce a satisfactory solution" (p.106). Carter and Fortune (2005) aimed to "establish how frequently partnering procurement is taking place and how appropriate it is considered for the delivery of sustainability" (p.183). Data were collected from a national survey of social housing providers to investigate their attitudes towards partnered procurement. The results showed that there was agreement that partnering could enable more sustainable procurement compared to conventional procurement approaches. For the present thesis, partnering was investigated at the case-study development as this was an important part of the design process, as shown in these two publications.

2.5.5 Summary

The literature reviewed in this section addressed the project team involved in the building design process. A third of the literature focused on the architects' perspective and did not consider other members of the project team even though a diverse range of professionals are involved in the design process, especially on low-energy building projects. Another publication focused just on the role of the environmental consultants, which presents the same issue. The majority of the publications used case studies as the main source of data collection. These ranged from one to 15 projects, many of which were not specified as being domestic or non-domestic. Interviews, surveys and observations were also used in many of the publications reviewed, with diaries, discourse analysis and content analysis used in a few examples.

Two of the publications reviewed were especially relevant to the present research as they both provided extensive detail of methods and results. In Wallace (1987) the methodology used to establish and analyse the interactions between project team members was provided. The study, however, focused solely on this aspect of the design team, rather than taking a more holistic view of the design process. Lowe et al. (2003c) examined a low-energy housing project using interviews with members of the project team from one case study to assess several aspects of their involvement in the design process. The report has not been published academically and although several publications have been produced from the research, none of them investigated the members of the project team and their influence on the process. The present thesis investigates the project team's involvement in the case-study, low-energy, private-sector housing development to establish the influence that these members have on the design process and the decisions made within that process. This issue has apparently not been explored in previous research.

2.6 Chapter conclusions

The publications reviewed in this chapter addressed a wide variety of areas related to low-energy housing and the design process. These publications, however, focused on individual and social housing projects due to the availability of data and a lack of examples of large-scale, private-sector development. Much of the literature related to the design process addressed non-domestic buildings, which are of a very different scale, process and funding structure to domestic buildings. There were also many publications that did not describe the methods used to collect and analyse data. Many publications also only focused on one specific part of the design process, or on one project team member's perspective (usually the architect's). This chapter has demonstrated a lack of research that investigated the design process to deliver private-sector, low-energy housing, which is critical in helping to mitigate the affects of climate change. Gaps seen in this literature, that the present thesis helps to fill, are as follows.

- Analysis of the entire design process for low-energy housing to see how this differs from the RIBA's *Plan of Work*, a well established design process model.
- Investigation of specific decisions that relate to the environmental impact of houses.
- Exploration of the involvement and influence of a range of project team members on the decision-making process and the design process as a whole.
- Investigation of the design process and the people involved in it, rather than addressing only one of these two elements.
- Creation of a revised model of the design process for low-energy housing using data from a case-study development and previous literature, applicable to future low-energy and zero-carbon housing developments.
- Collection of data that could form practical guidance for those involved in the design process of low-energy housing developments.

These elements provide some of the original contribution to knowledge made by the present thesis.

The most common method of data collection was the case study, with the majority of publications using a case-study approach of some sort. These included individual buildings, groups of buildings and people involved in the design process. Interviews, surveys and observations were used in several of the publications reviewed, with diaries, graphical information, discussion groups, discourse and content analysis used occasionally. Life-cycle analysis and multi-criteria decision analysis were also used in several publications where the necessary data were available or the researchers had control over the design process. Many of these methods were used in the present thesis. These are discussed in the detailed methodology provided in the Chapter 4 (p.59).

3. Case-Study Data Sources

In this chapter the data sources from the case-study development are presented. These data sources are used throughout the present thesis and are referred back to during the three results chapters:

- Chapter 5 – *A Design Process; incorporating sustainability*
- Chapter 6 – *Design Decisions: exploring decisions that affect the environmental impact of the houses*
- Chapter 7 – *Professionals in the Design Process; their perspective*

In this chapter the decision to choose a case-study approach is discussed and then the four data sources that form the components of the design process are presented: design team meetings, documents, project team members and construction team meetings.

3.1 Case study

A case-study housing development was used for the present research as it was an ideal source of data to achieve the research objectives described in Chapter 1 (section 1.1, p.11). Unique access was granted to the design process of the case-study housing development created by the industrial sponsor of the research, described in Chapter 1 (section 1.3, p.17). A case study is a type of field study defined as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context" (Yin, 2002, p.14). Case studies commonly see the researcher adopting several methods to collect data, including observation, interviews and documentary analysis (Robson, 2002). Yin (2002) described six sources of evidence that can be collected for case-study research: documents, archival records, interviews, direct observation, participant observation and physical artefacts. Yin states that these are "highly complementary" (Ibid, p.80) and that "a good case study will therefore want to use as many sources as possible" (Ibid, p.80) to enable triangulation of findings. The present research used documents, interviews and participant observation.

Case studies, however, do have their critics. Robert Stake was quoted, in the *Dictionary of Qualitative Inquiry,* as stating that that they were only useful to "generate knowledge of the particular" (Schwandt, 2001, p.23). However, Miller and Brewer (2003) described them as providing "some of the most interesting and inspiring research in the social sciences" (p.24).

In literature reviewed for the present research the majority of studies used case studies, either to investigate aspects of members of the design team (e.g. Macmillan et al., 2002) or building projects (e.g. Wallace, 1987; Bogenstätter, 2000; Yoklic and Carneval, 2003). Macmillan et al. (2002) set up two workshops each containing three interdisciplinary design teams to test a conceptual design framework created as part of the research. Several publications reviewed studied a single case-study (e.g. Yoklic and Carneval, 2003) but others used more than one (e.g. Wallace, 1987). Wallace (Ibid) used one longitudinal case study and several cross sectional ones to create a "complete and continuous picture of the group evolution" (Ibid, p.113) and "a series of windows of the current characteristics of the group at those points" (Ibid, p.113). The number of case studies used plays an important role in dictating the depth of the research being conducted: either an overview of a wide variety of cases or an in-depth analysis of very few cases. Ideally, for this type of research, it would be beneficial to obtain access to a number of design processes and provide an in-depth comparison. There are, however, problems with this approach as access to the design process is often restricted and to get as in depth an investigation as needed would take a lot more time and resources for several case studies. In the present research it was only possible to investigate one case-study in depth due to access to data as the studentship only involved one industrial collaborator and had limited resources this.

The level of access that the author of the present thesis was allowed to the case-study development was unusual due to commercial confidentiality issues that often preclude such access, but did not apply in the present research. As a result, a single case study was chosen using a longitudinal approach, rather than any attempt at comparing with other developments, where similar data would not have been easily available.

3.2 Data sources

This section describes the data sources available from the case-study development: design team meetings, documents, project team members and construction meetings.

3.2.1 Design team meetings

The design process for the case-study development was conducted through a series of design team meetings, from the detailed design stage of the case-study development until construction. These meetings were the main source of data for this study. Thirty-four design team meetings were attended by the author of the present thesis, who was embedded in the design process between April 2005 and November 2006 (20 months). The meetings were the forum for most of the decisions made in the design process, as this was when members of the project team gathered to make decisions. The majority of these meetings were based at the developer/client's office. The author of the present thesis attended design team meetings with the developer/client's permission, with access granted depending on the subject of the meeting.

The design team meetings that took place as part of the design process are listed in Table 3.1, which shows: the number of the meeting; the subject (given by the author of the present thesis from reviewing the notes of the subjects covered in each meeting); date; and length. There were several meetings that took place that the author of the present thesis did not attend. These were given the same number as the previous design team meeting, with a letter afterwards to signify that data were not collected from that meeting and are also shown in Table 3.1. These meetings were not attended for two main reasons: the author of the present thesis was not able to attend (5a, 9a and 28a); and the author of the present thesis was not asked to attend due to confidentiality reasons, usually concerning cost (11a, 11b, 11c, 12a, 12b, 21a and 21b). The average design team meeting, of those attended, lasted for 1 hour 50 minutes (110 minutes) and over 63 hours of meetings were attended in total.

Number	Subject	Date	Length (minutes)
1	Introduction to process	08/04/2005	105
2	Programme	15/04/2005	25
3	Updated programme	24/06/2005	60
4	Project Execution Plan (PEP)	01/07/2005	25
5	Briefing meeting	11/07/2005	100
5a	Data not available	22/07/2005	Data not available
6	Changes to designs	05/08/2005	120
7	Final changes to designs	12/08/2005	65
8	Phase 1 master plan	25/08/2005	150
9	Surfaces and finishes	30/08/2005	125
9a	Data not available	14/09/2005	Data not available
10	Standards and costs	23/09/2005	150
11	EcoHomes excellent	30/09/2005	115
11a	Data not available	03/10/2005	Data not available
11b	Data not available	06/10/2005	Data not available
11c	Data not available	13/10/2005	Data not available
12	Materials to be specified	14/10/2005	130
12a	Data not available	18/10/2005	Data not available
12b	Data not available	04/11/2005	Data not available
13	Risk workshop	28/11/2005	260
14	Programme	13/01/2006	125
15	Surface materials and EcoHomes	24/01/2006	215
16	Drainage and EcoHomes	27/01/2006	165
17	EcoHomes, procurement and tendering	03/02/2006	150
18	M&E drawings 1	06/02/2006	30
19	M&E drawings 2	10/02/2006	60
20	Infrastructure	11/04/2006	112
21	Achieving cost certainty 1	27/04/2006	50
21a	Data not available	02/05/2006	Data not available
21b	Data not available	16/05/2006	Data not available
22	Achieving cost certainty 2	23/05/2006	57
23	Achieving cost certainty 3	30/05/2006	125
24	Detailed specification	06/06/2006	110
25	Meeting with contractors	07/06/2006	100
26	Ground works	07/06/2006	190
27	Review of last 3 meetings	20/06/2006	60
28	Decision making to get to cost certainty	22/06/2006	160
28a	Data not available	04/07/2006	Data not available
29	Finance	04/08/2006	190
30	Resolving issues to get to construction	22/08/2006	100
31	Progress update	29/08/2006	60
32	Progress update and revise site plan	05/09/2006	75
33	Actions to get on site	17/10/2006	60
34	Pre-start meeting	07/11/2006	130

Table 3.1: Design team meetings attended

The distribution of design team meetings through the 86-week process is shown in Figure 3.1. This graph shows that the design team meetings were conducted in five different periods throughout the 86 weeks, these periods were created from reflecting on observations of the design process and notes taken at the meetings. The first period was the first two meetings which served as an introduction to the process. The second, meetings 3 to 13, concentrated on the programme and the environmental standard. The third, meetings 14 to 19, looked at the environmental standard and the M&E drawings. The fourth, meetings 20 to 27, focused on getting to the build cost and the fifth, meetings 28 to 34, looked at getting to site.

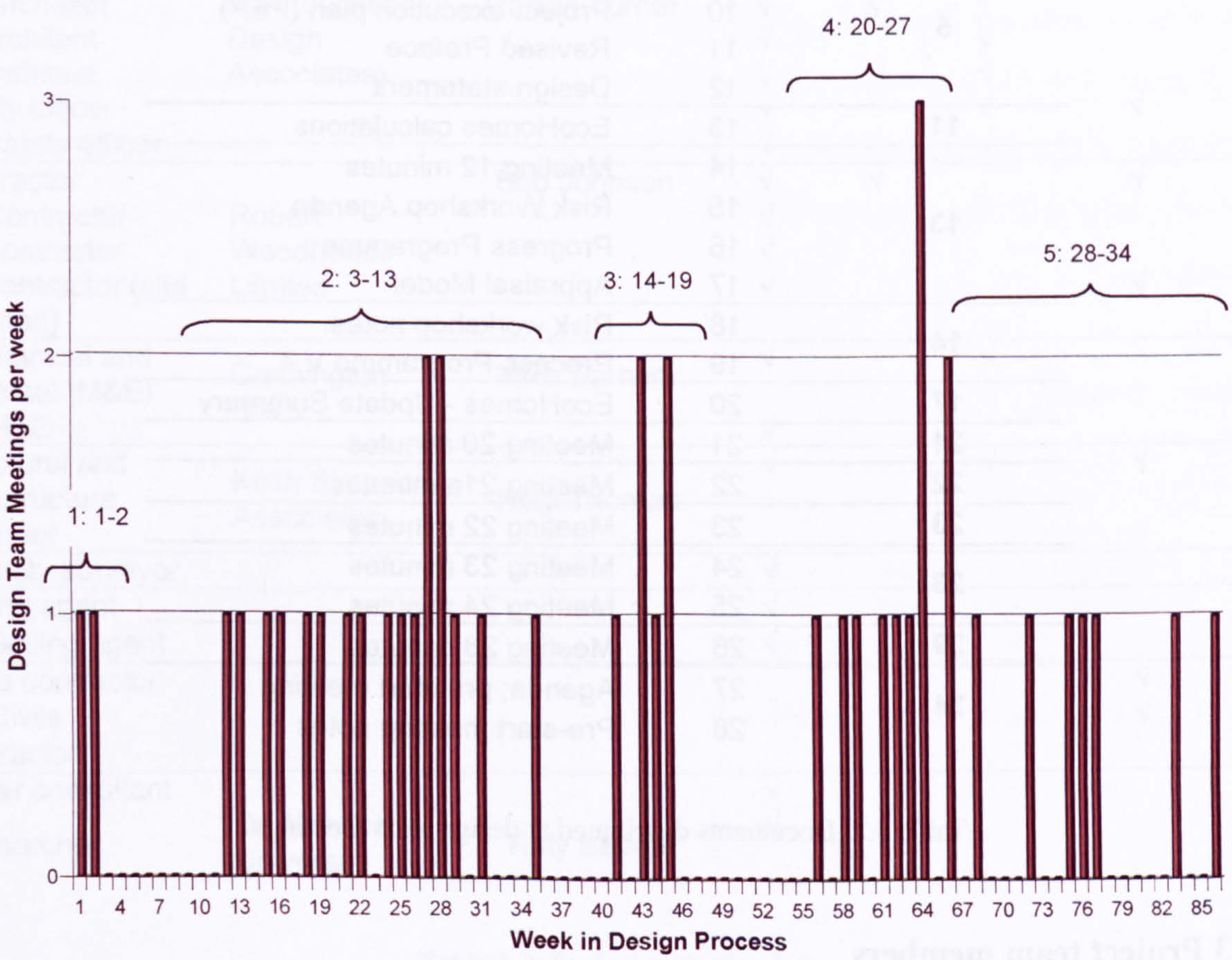


Figure 3.1: Distribution of design team meetings during the design process

3.2.2 Documents

The documents distributed during design team meetings are listed in Table 3.2, along with the design team meeting at which they were distributed and their number.

Design Team Meeting	Document Number	Document description
1	1	Minutes 24/03
	2	Working networks
	3	Contract arrangements
	4	Programme v.1
2	5	Meeting 1 minutes
	6	Design Drivers
	7	Programme v.2
3	8	Programme v.3
5	9	Agenda - briefing meetings
	10	Project execution plan (PEP)
	11	Revised Preface
	12	Design statement
11	13	EcoHomes calculations
13	14	Meeting 12 minutes
	15	Risk Workshop Agenda
	16	Progress Programme
	17	Appraisal Model
14	18	Risk workshop notes
	19	Process Programme V.4
17	20	EcoHomes - Update Summary
21	21	Meeting 20 minutes
22	22	Meeting 21a minutes
23	23	Meeting 22 minutes
28	24	Meeting 23 minutes
	25	Meeting 24 minutes
29	26	Meeting 28 minutes
34	27	Agenda; pre-start meeting
	28	Pre-start meeting notes

Table 3.2: Documents distributed at design team meetings

3.2.3 Project team members

The project team members who attended design team meetings are listed in Table 3.3 along with the team they belonged to. Those members who were interviewed for the research, analysis of which is provided in Chapter 7 (p.170), have two additional pieces of information provided: their name and the organisation they belonged to. Their permission was granted for these personal details to be given. The other members were informed of the research, but their consent was not requested for personal information to be provided. The numbers given to some of the roles relate to the fact that there were several project team members fulfilling these roles and does not relate to their position or status in the organisation or on the project.

Role	Organisation	Name	Team: Project	Core	Design	Construction
Client (main)	SEV (Sherwood Energy Village)	Stan Crawford	√	√		√
2nd Client		Carla Jamison	√			
Project manager	JDA (Jackson Design Associates)	Alan Gammon	√	√	√	√
Principal architect		Tony Jackson	√		√	
Job architect		Darren Turner	√	√	√	
3rd Architect			√		√	
4th Architect			√		√	
Safety officer			√		√	√
2nd Safety officer			√		√	
Contractor	Robert Woodheads Limited	Bob Johnson	√	√		√
2nd Contractor			√			
3rd Contractor			√			
4th Contractor (site foreman)			√			√
Mechanical and electrical (M&E)	Cunnington Clark	Mike Barham	√		√	
2nd M&E			√			
Structural and infrastructure engineer	Keith Simpson Associates	Neal Thomas	√		√	√
Quantity surveyor			√			
Selling agent			√			
2nd Selling agent			√			
Civils contractor						√
2nd Civils contractor						√
Water consultant			√			
Researcher	De Montfort University	Katy Beadle	√			

Table 3.3: Project team members

Appendix A (p.265) details the design team meetings attended by each of the project team members.

The following definitions are used to describe different groups who were involved in the design process. The project team refers to everyone who was involved in the design process. The core design team refers to those members who were able to finalise decisions within the design process. The design team refers to the architects and engineers involved in the project. The construction team refers to those members of the project team who were responsible for the construction of the project.

3.2.4 Construction meetings

Construction meetings commenced after all the design team meetings were undertaken and construction started on site. Nine construction meetings were attended by the author of the present thesis between November 2006 and February 2007 (4 months). These meetings took place on the site of the housing development and were attended to track the outcome of decisions made in the design team meetings. Table 3.4 shows the construction meetings attended, along with the date on which they took place, their number and the length of the meeting.

Number	Subject	Date	Length (minutes)
1	Pre-start construction meeting: construction programme	15/11/2006	90
2	Construction progress meeting 1: actions to be completed	21/11/2006	55
3	Construction progress meeting 2	05/12/2006	65
4	Construction progress meeting 3	19/12/2006	90
5	Construction progress meeting 4	09/01/2007	70
6	Decision meeting 1	16/01/2007	60
7	Construction progress meeting 5	06/02/2007	75
8	Decision meeting 2	06/02/2007	80
9	Decision meeting 3	21/02/2007	90

Table 3.4: Construction meetings held at the case-study development

The construction meetings were attended by some of the same people who attended the design team meetings, listed in Table 3.3. As the emphasis was on construction these meetings were always attended by the contractor and the site foreman, as well as the project manager. These meetings often included the civil engineers used for the site as well as the plumbing and heating engineers and electrical contractors. The client and the fourth architect also attended several meetings, but the other architects, M&E consultants and the structural and infrastructure engineer were not present.

3.3 Chapter summary

This chapter has summarised the data that were available from the case-study development used in the present research, as well as justifying the use of the case-study development. These data formed the core of the research and are used and referred back to throughout the present thesis.

4. Methodology

To establish how low-energy housing could be delivered on a large-scale private-sector development, a mixed-methods approach was employed to achieve the research objectives presented in Chapter 1 (section 1.1, p. 11). The case study, discussed in section 1.3, was selected as it provided unique access to the design process of a low-energy housing development being developed by the industrial sponsor of the present research. Data were available from a wide range of sources, described in Chapter 3 (p.49), which enabled the objectives for the present research to be achieved. Design team meetings were the main component of the design process which was studied. Data were collected from these meetings via direct observation and collection of documentary materials distributed during the meetings. Interviews with members of the project team involved in the decision-making process were undertaken to add to these data sources.

In this chapter the terms 'method' and 'methodology' are used to explain two separate entities. Method "denotes a procedure, tool, or technique used by the inquirer to generate and analyse data" (Schwandt, 2001, p.158), such as template analysis. Methodology "connotes a set of rules and procedures to guide research" (Miller and Brewer, 2003, p.192), which could be all the parts that make up the data collection and analysis of a set of interviews, as is the case in Chapter 7. In the present thesis, each of the empirical chapters (5, 6 and 7) has a particular methodology, or overarching approach. Each methodology uses a variety of methods to collect and analyse data.

In this chapter the mixed-methods approach is discussed followed by a discussion of each of the methods used in the present research. The methodologies for the following three results chapters: 5, *A design process: incorporating the high environmental standard*; 6, *Design decisions: exploring decisions that affect the environmental impact of houses*; and 7, *Professionals in the design process: their perspective*, are then described and then alternative methods are presented and briefly discussed.

4.1 Mixed-methods approach

A mixed-methods approach to research "is the notion of using multiple methods to generate and analyse different kinds of data in the same study – for example, combining a narrative analysis of in-depth interviews with a content analysis of questionnaire responses" (Schwandt, 2001, p.164). The methods used in the present research were informed by those used in previous literature, discussed in Chapter 2 (p.25). Several of these were combined to create a mixed-methods approach. A mixed-methods approach is seen as having "substantial advantages" (Robson, 2002, p.370), especially when qualitative and quantitative methods are used in unison for triangulation. Triangulation is "a procedure used to establish the fact the criterion of validity has been met" (Schwandt, 2001, p.257). Schwandt further states that "different ways of framing and studying social phenomena yield different kinds of understandings" (p.165), which should engage with one another and "not simply be tolerated as different" (Ibid, p.165).

4.2 Methods

In this section the methods used in the present thesis are discussed. An introduction to each method is provided, along with examples of its use in previous literature, followed by details of how it was used in the research.

4.2.1 Participant observation

Participant observation consists of the researcher observing a social situation, whilst participating in it at the same time. The information gathered from studying the social situation should be "enhanced through introspection by the researcher who undergoes the same experiences, attitude changes and events as people under study" (Miller and Brewer, 2003, p.222). Participant observation is often used in ethnographic field studies. Ethnography is "the process and product of describing and interpreting cultural behaviour" (Schwandt, 2001, p.179). Although the design process is not a culture, it can be seen as a micro-culture with its own rules and norms. Robson (2002) stated that "as the actions and behaviours of people are central aspects in virtually any enquiry, a natural and obvious technique is to watch what they do, record this in some way and then to describe, analyse and interpret what we have observed" (p.309). Participant observation is described as "a methodology that includes activities of direct observation, interviewing, document analysis, reflection, analysis, and interpretation" (Schwandt, 2001, p.186). Although participant observation has been criticised for making the researcher "an intervening variable" (Miller and Brewer, 2003, p.222) who lacks objectivity, Robson (2002) states that "objectivity can be approached through a heightened sensitivity to the problem of subjectivity, and the need for justification of one's claims" (p.322). It is also recommended that a researcher keep "some respectful distance from those studied" (Schwandt, 2001, p.186) to maintain an objective view.

In the literature reviewed, observation was used in various ways. The majority of researchers observed their case studies directly. Participant observation was used by Lowe et al. (2003c), with all other literature using non-participant observation. Non-participant observation was used by Gorse et al. (2001) to collect data from at least three meetings per case study identified. Wallace (1987) used it to observe meetings and was able to record these to provide quotes for qualitative analysis. Lowe et al. (2003c) was the only study identified that used video recording for some of the data collection; otherwise either tape recordings or notes were made. Macmillan et al. (2002) used non-participant observation to collect data from design team meetings as well as workshops and Misra (2002) used it to study seven individual houses over several years of their development. Observation, be it direct or indirect, participant or non-participant, provides a wealth of information. Access is key to collecting data via observation as it can be obtrusive, distracting and unwanted and can have an impact on confidentiality, honesty and openness. Efforts were made to minimise these problems throughout the research reported here.

Participant observation was used by the author of the present thesis to collect data available at the design team meetings to enable in-depth analysis of the design process. The author of the present thesis was embedded within the design process for 22 months. Nason and Golding (1998) state that the observer must be reflective and attempt to understand how "prior values and knowledge influence what is observed, whilst observing" (Ibid, p.235).

Subjectivity was consciously reviewed through self awareness of the author of the present thesis and was taken seriously. The following measures, informed by Robson (2002, p.322-325), were undertaken to minimise subjectivity in analysis and reporting.

- The client read all design team meeting notes made by the author of the present thesis to check for subjectivity.
- The design team meeting notes were cross-referenced with minutes from the meetings to check they were consistent.
- Distribution of the author of the present thesis's attention was spread widely and evenly.
- The author of the present thesis could see all project members in the meetings and the seating position of team members changed at every meeting.
- Field notes from the meetings were summarised into a narrative straight after the meetings, and written-up thoroughly as soon as possible after meetings.
- Interpersonal factors were acknowledged and efforts were made to ensure that they did not bias analysis or reporting.

The role of the author of the present thesis in the meetings was to observe the design process and contribute where necessary. The contribution of the author of the present thesis varied depending on the type and topic of the meeting. On occasion this involved the author of the present thesis going away and working on something for the next meeting (e.g. timber policy or checking the mechanical and electrical (M&E) specification). Documentation of design team meetings was initially going to be via the use of a digital voice recorder, which was used for the first few meetings. The recording of meetings was suspended, however, because of the sponsor's concerns over intellectual property rights (IPR). These were not resolved, so recording did not recommence. Written notes were used to collect data from the design team meetings, with as much information as possible recorded, including corresponding what was being said with who was saying it as well as a note of the time recorded at five-minute intervals. In each meeting a number of other pieces of information were collected, including: date, time and length of meeting; attendance;

seating plan; documents referred to and distributed; and details of the next meeting. These were written up into a page summary for each meeting straight after the meeting had finished. An example is shown in Appendix B, p.266.

4.2.2 Interviews

Interviews "provide a way of generating data by asking people to talk about their everyday lives" (Miller and Brewer, 2003, p.166). There are various types of interviews: structured, semi-structured and unstructured. These provide varying extents of depth and flexibility of responses (Robson, 2002). Unstructured informal interviews are commonly used in qualitative research, but more structured interviews are suited to case studies where "time is limited or where it is desirable to obtain some specific or focused information" (Schwandt, 2001, p.135). Interviews with various members of project teams were undertaken in the studies reviewed. These ranged from interviews with just the architect or client, to interviews with the whole project team. Lowe et al. (2003c) used unstructured interviews with planning and building control officers as well as semi-structured interviews with the selected project team members. Wallace (1987) used semi-structured interviews with architects at two stages of the design process and Fortune and Welham (1995) used them to explore the environmental awareness of 30 architects, quantity surveyors and mechanical and electrical engineers. Mackinder and Marvin (1982) did not specify what structure of interview was used, but interviewed architects to explore their role in the design process. Interviews give the opportunity for the researcher to talk one-to-one with research participants, which can provide valuable data that are precise and honest. Interviews are, however, time consuming and questions posed can be seen as intrusive by the interviewee. There is also a risk that data may not reflect participants' true thoughts and feeling and it is very difficult to know when this is the case, although triangulations with other data sources can help.

In total, 22 people were involved in design team meetings at the case-study development. However, it was observes that only a small number of members in the project team who significantly influenced design decisions made about the houses. Seven project team members were interviewed using semi-structured interviews. These are shown in Chapter 7, (Table 7.1, p.171) along with the date, location and length of the interview. Interviewees were chosen following recommendations from the client/developer. The author of the present thesis agreed that these people were most involved in the design process. Ideally, interviews would have been conducted at several intervals during the design process to add a longitudinal element to the data and to investigate any change in knowledge and attitudes to the high environmental standard and the project team. Unfortunately this was not possible due to the sponsor's wishes and contractual issues surrounding the relationships within the team. Interviews were therefore only undertaken following contracts being put in place between all organisations involved in the design process. This was a requirement laid down by the client/developer who was the gateway to the other parties involved in the design process. Interviews were conducted between November 2006 and February 2007 in a location of the interviewees' choice, to enable them to feel comfortable and relaxed. The interviews were recorded using a digital voice recorder and files were stored in a safe and secure location. The author of the present thesis conducted all interviews to reduce bias and increase familiarity as the author of the present thesis was known to the project team members. The length of the interviews ranged from 30 to 95 minutes with an average of 57 minutes.

Prior to the interviews being organised, members were given an introduction to the purpose of the interview and were asked their permission for the interview to be digitally recorded. Questions were informed by literature reviewed for the present research, with four publications being key. Mackinder and Marvin (1982) used interviews with architects to understand the role of information, experience and other influences on the design process. Open-ended questions were used at intervals throughout the design process and the architect was encouraged to lead the discussion. Wallace (1987) investigated the interactions between design team members, using open-ended questions focusing on the role of the architect that were informed by observations of design team interactions. Fortune and Welham (1995) assessed the environmental awareness of 30 construction professionals using 15-minute structured interviews looking at background subject information and general environmental awareness of terms, organisations and issues. Lowe et al. (2003c) used open-ended interview questions with project team members of a housing development to enhance understanding of the impact that a new environmental standard being implemented had on them and the design and construction process.

The questions for the interviews were informed by these publications so that the questions chosen had already been tested and the answers could be used for comparison, with previous research. They were also influenced by issues explored in other literature reviewed, and by the research objectives. The literature as a whole tended to focus on four issues: personal background and involvement; change in general views and attitudes; knowledge, skills and understanding; and perception of the design process. The questions used in the interviews are detailed in Appendix C (p.267) under four sections:

- Background information
- The project and standards
- Design decisions
- Lessons and barriers

The questions from the first section (background information) were investigated in several of the publications reviewed, including Lowe et al. (2003c) and Fortune and Welham (1995), who asked very similar questions which informed the question: *What is your prior experience of low-energy projects, if any?*

The second section focused on the project and the environmental standard and these questions were informed by the research aims and objectives. For example, one question was: *Focusing on the standard set for the project (EcoHomes excellent), what would you say the key elements are for the successful implementation and delivery of this standard?*

The third section (design decisions) was influenced by the research aims and objectives as well as Lowe et al. (2003c) and Mackinder and Marvin (1982), who asked similar questions. An examples question form this section is: *What would you say motivates the decisions you make (or help to make) within the design process?*

Section four focused on lessons and barriers and the questions in this section were informed by a wish to influence future low-energy housing developments. For examples: *What lessons do you think have been learnt from this project about designing and building low-energy housing?*

The questions developed for the interviews were assessed by eight colleagues and pilot interviews were undertaken with four of these colleagues who had an understanding of the design process, and with two members of project teams who also carry out academic research. These pilots were used to assess whether questions were clear, understandable and whether the structure and flow of the interview was acceptable. The interviews with members of project teams also gave an insight into the relevance of the questions to the design process as a whole. Questions were revised accordingly based on these pilots. All questions were open-ended to enable the participant to answer freely and provide as much information as s/he felt necessary. Additional questions were asked if the author of the present thesis felt that more information on a particular question was necessary or if an interesting line of discussion was developing that was not covered by the questions.

Template analysis, described in section 4.2.3, was undertaken on the interview transcripts, the results of which are detailed in the introduction to Chapter 7 (p.171), where the analysis of interview data is discussed.

Prior to the interviews being transcribed, a page summary of each interview was produced to outline the key themes and points of the interview. This was undertaken straight after the interviews, to note down any thoughts and feelings about the interview whilst fresh in the author of the present thesis's memory, as recommended in Robson (2002). The digital voice recordings were transcribed by the author of the present thesis as soon as possible after the interview to enable in-depth analysis. The interviews were transcribed as thoroughly as was needed for the analysis, with all words transcribed apart from unintended repetitions and filling sounds, such as 'erm' and 'ah'. The interview transcripts were sent to the interviewees for verification that the author of the present thesis captured what was actually said during the interviews.

4.2.3 Template analysis

Template analysis "refers to a particular way of thematically analysing qualitative data" (King, 2006). In template analysis a "list of codes that represent themes identified in the textual data" (King, 1998, p.118) is created, with some of these potentially being defined before analysis and others developed as the text is read and interpreted. In the present thesis an adapted version of King's (2006) seven step approach to template analysis was used. An adapted version of the approach was used as King focused on interview transcripts rather than detailed notes from participant observation, although he states that the method "can be used with any kind of textual data" (Ibid, p.133). The adapted nine-step approach followed by the author of the present thesis is outlined below and was used on design team meetings notes, documents and interview transcripts for the three results chapters (5, 6 and 7) that follow this chapter.

1. Predefine terms

A set of predefined terms for coding were developed. These were then grouped into broader themes for analysis.

2. Type up notes

Data were typed up as soon as possible after collection.

3. Initial coding

Initial coding was conducted by hand, using the predefined codes. These were applied to all notes/transcripts. Relevant text that related to the research objectives was either assigned an existing code, or if a particular piece of text did not fit an existing code, a new code was created to classify the text and that code was added to the existing codes when coding the rest of the data.

4. Initial template

An initial template was created from the codes used in step 3. Predefined codes outlined in stage one were removed if they were not applicable to the data collected. Lower order codes were also added to provide greater specificity where required.

5. Develop template

The template was developed by re-examining all the data, identifying text relevant to the research objectives, and adding the appropriate code from the initial template. The template was modified as this process progressed, to remove any inaccuracies in the template. Four types of modification were needed to develop the template.

- A new code was inserted as text relevant to the research objectives was found, but there was no existing code to label it.
- A code was unnecessary or there was substantial overlapping so it was deleted.
- A code's scope was too narrow or broad and so it was redefined.
- A lower-order code was transferred from one higher-order code to another.

6. Validate template

The developed template was validated to make sure that it was appropriate for use. The main strategy to validate the template was inter-coder reliability, which involved asking an external advisor who knew the research and had experience of analysing qualitative data to see if the template was sufficiently clear and comprehensive. This external advisor was asked to code a selection of the data using the developed template. He then made any comments about the process of coding the text using the developed template, which was then discussed and revised where necessary. A formula is sometimes used to assess the level of agreement between the author of the present thesis and the advisor concerning codes applied to the text. However, agreement and disagreement can also be discussed rather than quantified, as there are always a variety of ways of reading a text (Robson, 2002).

7. Final template

The final template was created after validation was completed with the external advisors comments considered.

8. Interpret coded data

The coded data were interpreted by first listing all codes present in a particular meeting/document/interview, to draw attention to issues of particular importance. The codes that were seen to be most relevant to the research objectives were focused on, with those that were not relevant discarded.

9. Write up and present findings

The write up and presentation of the interpretation of the texts has the final step in the analysis. This involved summarising the notes made about the codes, selecting illustrative quotes and producing accounts of the findings. These accounts were based on the main themes identified and then illustrative examples were drawn for the data. Efforts to maintain objectivity were made using the techniques listed in section 4.2.1.

4.2.4 Documentary analysis

Documentary analysis looks at texts produced in relation to the culture or setting being researched. These are often generated by the culture itself, which may be self-documenting (Atkinson and Coffey, 2004). It is not uncommon for ethnographic research to rely entirely on non-documentary evidence, as though it does not exist, which leads to studies that do not "do justice to the settings they purport to describe" (Ibid, p.56). Documents are usually used to confirm areas of interest to the researcher, as they have a tendency to be shrouded in subjectivity (Knight, 2002). Documentary analysis was used in several of the reviewed studies, mainly to supplement data collected from other sources. These documents often formed part of the design process and included: design documents (Lowe et al., 2003c), design briefs (Mackinder and Marvin, 1982), minutes from design team meetings (Wallace, 1987) and regulations (Hamel, 1994). Documentary analysis is a good method of supplementing data collected from different sources, such as interviews, observation or questionnaires (Atkinson and Coffey, 2004). Relying on this evidence alone, however, can be unwise, as it will rarely give the whole picture and may be biased towards the producer of a particular document (Ibid).

Documents were distributed at design team meetings by various parties for the attention of project team members. These documents provided additional information to that obtained through observation of design team meetings, which assisted in validating the notes taken by the author of the present thesis. Template analysis was used to analyse these documents, following the steps described in section 4.2.3. The results of this process are detailed in the introduction to Chapter 5 (p.83), where the findings from the analysis of these documents is discussed.

4.2.5 Content analysis

Content analysis is the analysis of message characteristics that is used in many areas of research and has been growing particularly rapidly in the mass communication field (Neuendorf, 2002). It is used to provide a "relatively systematic and comprehensive summary or overview of the data set as a whole, sometimes incorporating a quantitative element" (Wilkinson, 2004, p.182). Content analysis was undertaken by coding textual data so that the number of occurrences of a particular code could be counted for quantitative analysis, or the codes could be compared and further analysed as part of qualitative research (David and Sutton, 2004). Content analysis was used by two of the publications reviewed in Chapter 2 to analyse interactions between design team members through the design process. Wallace (1987) used a combination of six techniques to explore the interactions in design team meetings and Gorse et al. (2001) used one specific method to "observe, analyse and interpret social interactions" (p.763). Content analysis can be used in a number of ways, but in the present research it was used to give a simple quantitative measure of how often a given theme from the data was discussed. The data could have been analysed using a more complex form of qualitative content analysis to look at the interactions between design team members, but due to the amount of data collected from the design team meetings (over 63 hours) this would have been a very time consuming task and would not have directly achieved any of the research objectives.

4.2.6 Decision analysis

None of the studies reviewed described the methods used to analyse decisions, even though many of them tackled decision making, as discussed in Chapter 2 (section 2.4, p.38). The decision analysis used in the present research identified the phases of the decision making process using a model developed by Mintzberg, Raisinghani and Théorêt (1976). The model was developed by investigating the decision processes of 25 case studies together with a review of empirical literature. The decision processes studied were from a range of organisations including manufacturing, services and government. The investigation also consisted of several decision processes from design projects, which were described as the most complex and included the development of a bank headquarters (Mintzberg et al., 1976). This model was deemed appropriate to analyse the decisions made in the design process of the case-study development. The model developed by Mintzberg et al. (Ibid) was presented in a more practical form in Jennings and Wattham (1994). This version was used to analyse the decisions made in the design process that affect the environmental impact of the houses. The model has three phases that underpin 'unstructured' decision making in organisations, which are presented below (Jennings and Wattham, 1994 p.10).

1. Identification:
    - Recognition that a decision needs to be made.
    - Diagnosis of the nature of the situation, which may be done by the organisation itself or by an external consultant.
2. Development:
    - Search for ready-made solutions to the problem; starting with sources that are local and immediately accessible and extending this search if necessary.

    - Design new solutions or modify those in existence, which is often expensive and time consuming.
3. Selection:
    - Screen ready-made alternatives.
    - Evaluate/choose ready-made alternatives and new solutions.
    - Authorise a decision through the hierarchy of the organisation and sometimes outside the organisation.

Decisions were also analysed by answering a set of questions outlined by Jennings and Wattam (1994, p.25).

- When was the problem first recognised?
- How was it diagnosed?
- What was the problem?
- Was the problem redefined in the course of the decision?
- Over what period of time did the decision take place?
- Were there delays and hold-ups in making the decision?
- Why did these occur? Did they change the decision?
- Which were the most significant stages? Were all stages well handled?
- Who was involved in the decision?
- Were several organisations involved? How did they affect the decision?
- How well was the decision made in terms of meeting the problem and furthering the objectives of the organisation? Could the search activity have been better conducted to identify further feasible alternatives?
- At what stage and how was the choice of a solution made?

These two types of decision analysis were undertaken on the key decisions that affected the environmental impact of the houses identified through template analysis. The results of this process are detailed in the introduction to Chapter 6 (p.127), where the analysis of these results is discussed.

4.3 Methodologies for subsequent results chapters

The methods described in section 4.2 are used in various combinations to create methodologies for the three subsequent results chapters:

- Chapter 5, *A Design Process: incorporating the high environmental standard*
- Chapter 6, *Design Decisions: exploring decisions that affect the environmental impact of houses*
- Chapter 7, *Professionals in the Design Process: their influence*

The combination of the methods used in each methodology is described in this section and a graphical representation of each is presented.

4.3.1 Chapter 5, *A Design Process: incorporating the high environmental standard*

In Chapter 5, *Design Process: incorporating the high environmental standard* template analysis of the design team meetings was combined with documentary analysis of documents distributed and quantitative content analysis, described in section 4.2. These were combined, analysed and discussed to form the results chapter. This process is represented in Figure 4.1. This diagram shows the sequence of data collection, analysis, interpretation and discussion for the chapter. The themes discussed relate to elements through which the high environmental standard can be incorporated in the design process. The process of discovering these themes through template analysis is explained in more detail in the introduction to Chapter 5 (p.83).

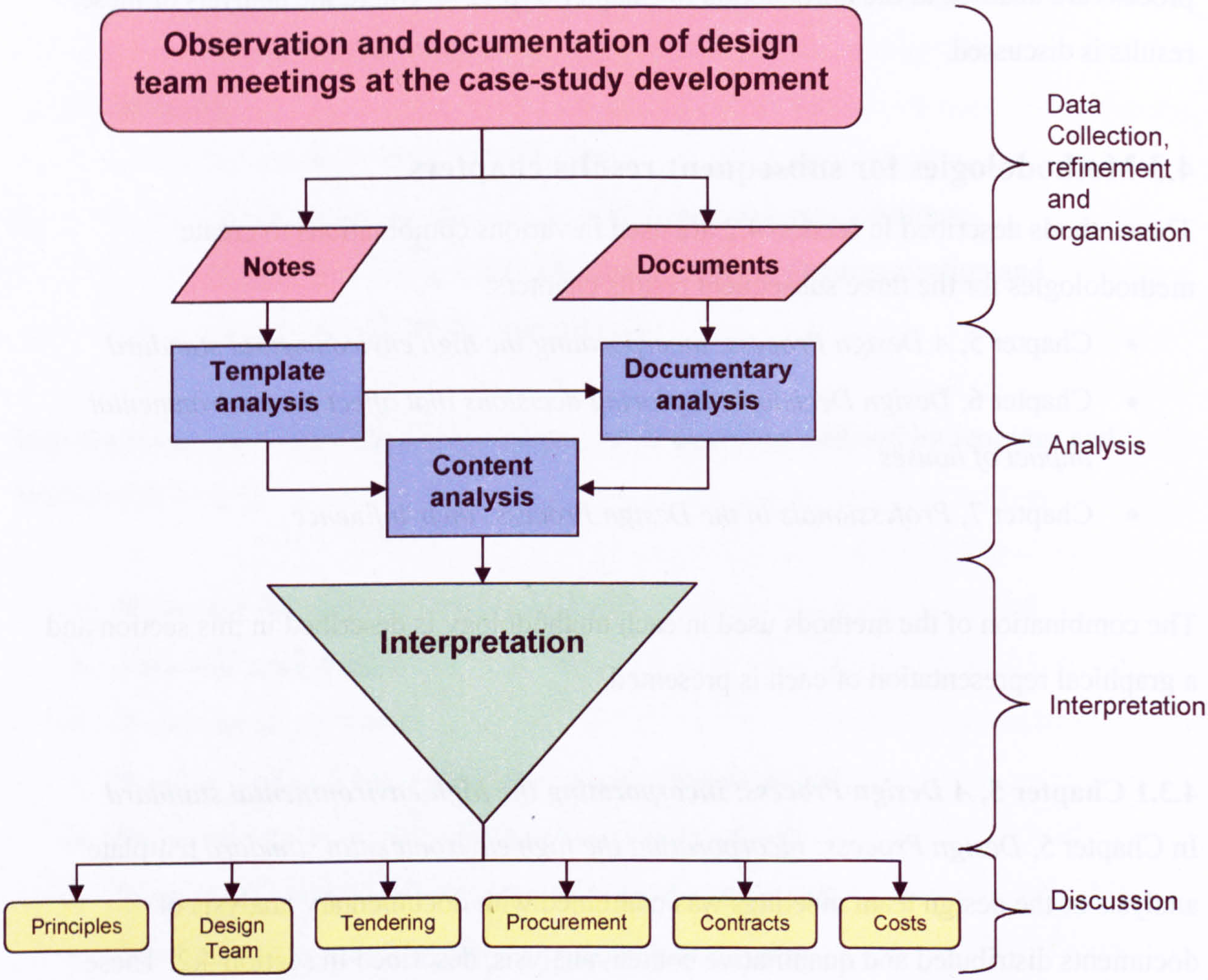


Figure 4.1: Methodology for Chapter 5, *A Design Process: incorporating the high environmental standard*

The interpretation of the various findings brings together the analysis undertaken using the multiple-methods approach. This resulted in a presentation of all the factors that contribute to these elements of the design process. Findings from the various analysis techniques were then condensed to focus on the main areas of interest relating to the research objectives.

4.3.2 Chapter 6, *Design Decisions: exploring decisions that affect the environmental impact of houses*

Template, documentary and decision analysis were combined in Chapter 6, *Design Decisions: exploring decisions that affect the environmental impact of* houses. These were combined to form the basis of the results chapter, represented in Figure 4.2. The discussion involved products of the design process, rather than the components of the design process outlined in section 4.3.1. This analysis is described in more detail in the introduction to Chapter 6 (p.127).

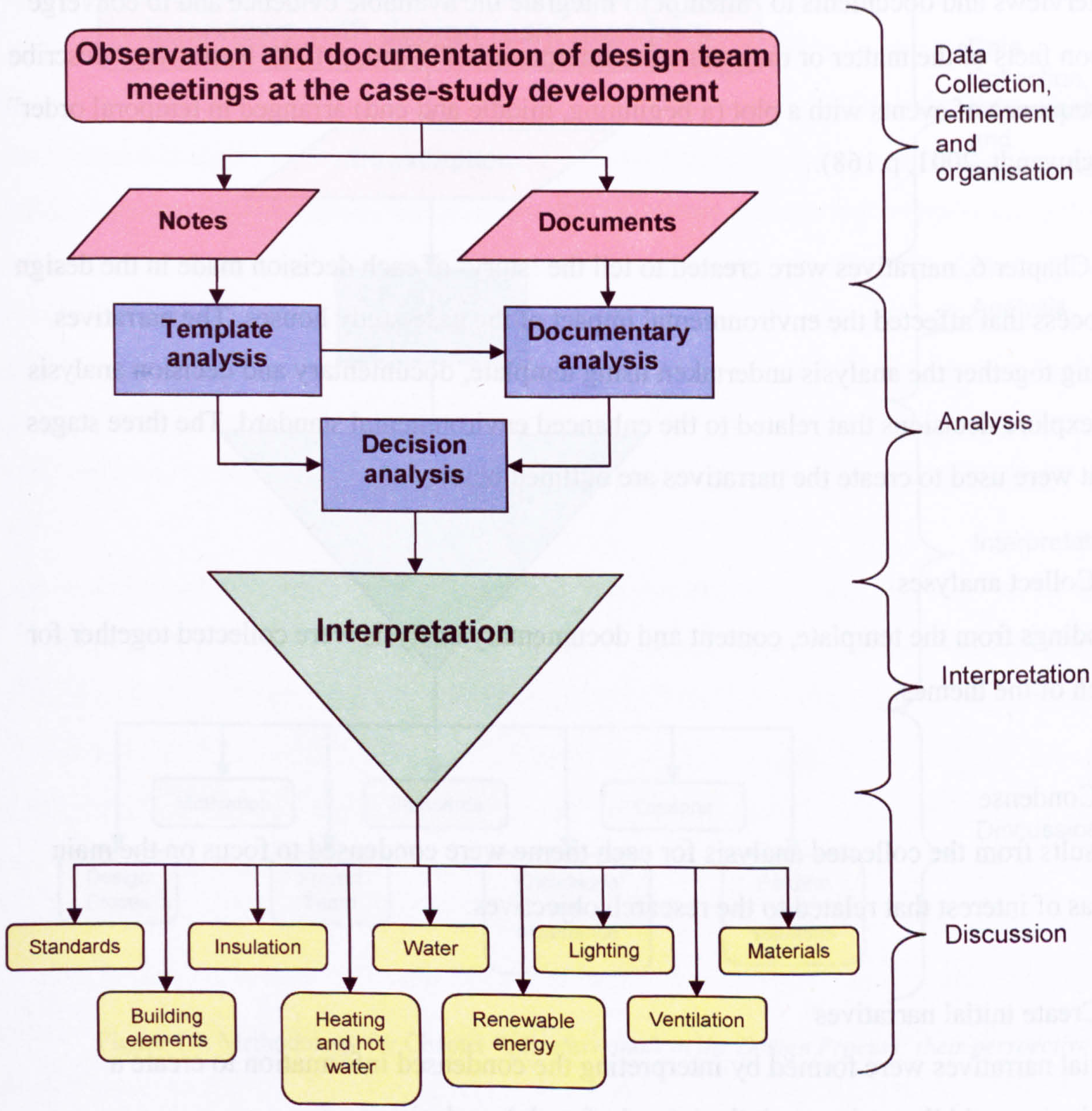


Figure 4.2 Methodology for Chapter 6, *Design Decisions: exploring decisions that affect the environmental impact of the houses*

The discussion in Chapter 6 is on the notion of narratives. Narratives are described by Yin (1994) as an analytical process that forms part of creating a case-study database, presented as one of three principles of data collection. Creating narratives consists of a process where research objectives are achieved by combining relevant evidence such as observation, interviews and documents to "attempt to integrate the available evidence and to converge upon facts of the matter or their tentative interpretation" (Ibid, p.104). Narratives "describe a sequence of events with a plot (a beginning, middle and end) arranged in temporal order" (Schwandt, 2001, p.168).

In Chapter 6, narratives were created to tell the 'story' of each decision made in the design process that affected the environmental impact of the case-study houses. The narratives bring together the analysis undertaken using template, documentary and decision analysis to explore decisions that related to the enhanced environmental standard. The three stages that were used to create the narratives are outlined below.

1. Collect analyses
Findings from the template, content and documentary analysis were collected together for each of the themes.

2. Condense
Results from the collected analysis for each theme were condensed to focus on the main areas of interest that related to the research objectives.

3. Create initial narratives
Initial narratives were formed by interpreting the condensed information to create a beginning, middle, and an end: the 'story' of each key decision.

4.3.3 Chapter 7, *Professionals in the Design Process: their influence*

Template analysis of the interview transcripts formed the basis of Chapter 7, *Professionals in the Design Process: their influence.* The methods used are represented in Figure 4.3

which shows the sequence of data collection, analysis, interpretation and discussion for the chapter. This analysis is described in more detail in the introduction to Chapter 7 (p.171).

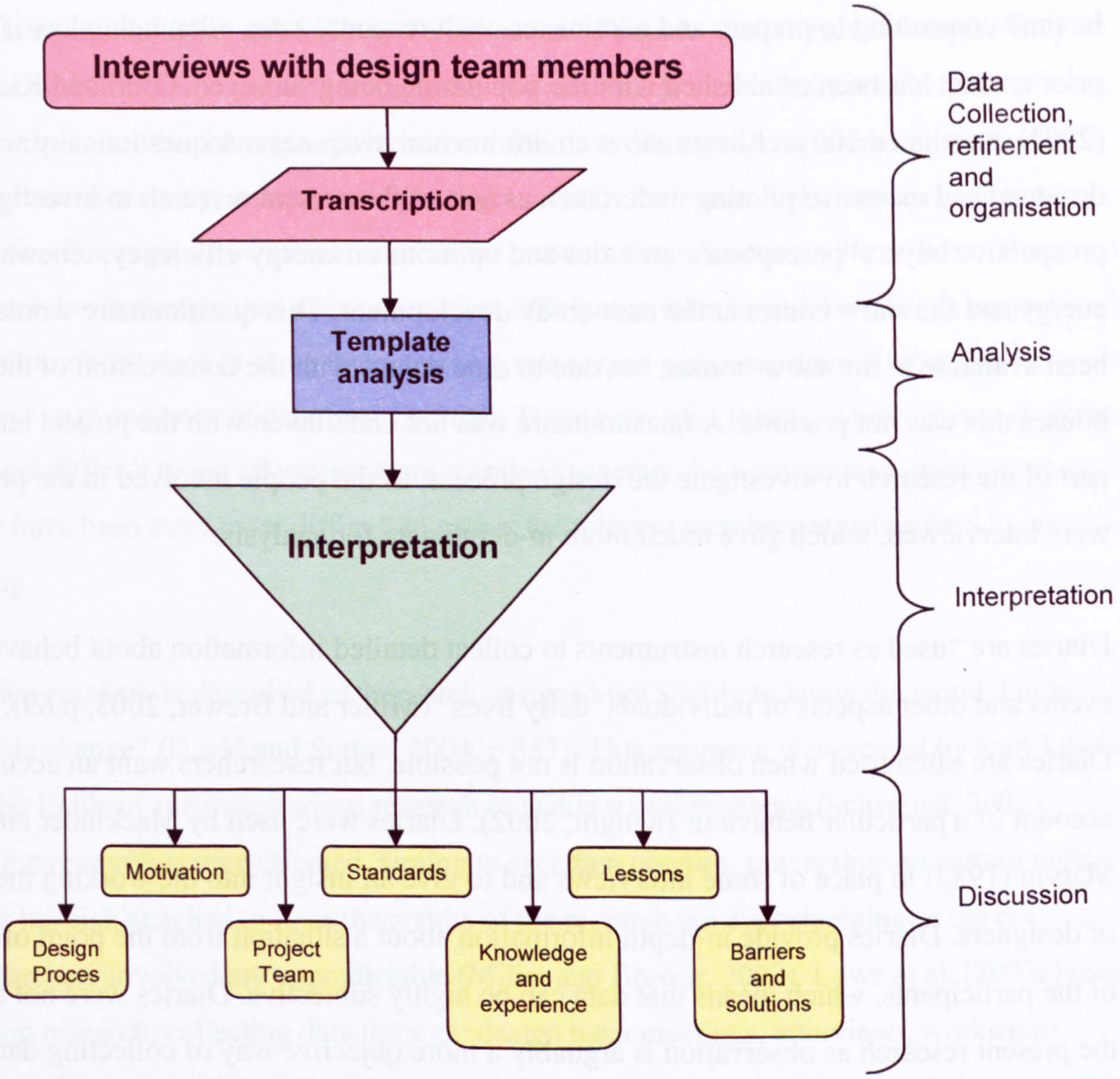


Figure 4.3: Methodology for Chapter 7, *Professionals in the Design Process: their perspective*

4.4 Alternative methods

This section briefly outlines some alternative methods that could have been used to collect and analyse data for this research. Each is described and an example of its use is identified from the literature reviewed. Justification for not using these methods is then provided.

Questionnaire surveys have been carried out to obtain data for hundreds of years (Robson, 2002). Questionnaire surveys are usually used to obtain data from a large number of participants that would be difficult to collect any other way. Questionnaires can, however, be time-consuming to prepare and administer, with response rates often being low if no prior contact has been established with the population being surveyed. Ofori and Kien (2004) questioned 100 architects about environmental awareness. A questionnaire was also designed and extensive piloting undertaken as part of the present research to investigate prospective buyers' perceptions, attitudes and opinions on energy efficiency, renewable energy and the show homes at the case-study development. This questionnaire would have been available in the show-homes, but due to time delays with the construction of the houses this was not possible. A questionnaire was not undertaken with the project team as part of the research to investigate the design process, as the people involved in the process were interviewed, which gave much more in-depth data for analysis.

Diaries are "used as research instruments to collect detailed information about behaviour, events and other aspects of individuals' daily lives" (Miller and Brewer, 2003, p.69). Diaries are often used when observation is not possible, but researchers want an accurate account of a particular behaviour (Knight, 2002). Diaries were used by Mackinder and Marvin (1982) in place of some interviews and to give an insight into the working methods of designers. Diaries provide in-depth information about a situation from the point of view of the participants, which means that data can be highly subjective. Diaries were not used in the present research as observation is arguably a more objective way of collecting data, especially in a situation where time, money and access to data were not problematic issues, which they often are. Diaries were also felt to be very intrusive in the design process as the project team members would have needed to spend a considerable amount of time compiling them. The author of the present thesis was keen not to take up much of the project team members' time and did not want to impose any extra task upon them.

Focus groups are "a research approach whereby a group of individuals are selected to discuss together, in a focused and moderated manner, the topic under research" (Miller and

Brewer, 2003, p.120). The researcher invites the group to attend and often explores provisional findings by describing them to participants or by discussing findings with a group of stakeholders involved in the study (Knight, 2002). Lowe (2003c) conducted focus groups with the design team during the design phase. Focus groups are a good way of obtaining the thoughts and feeling of a collection of people about a research topic. They are, however, time-consuming to organise and analyse. If the analysis is to include a transcription of the focus group, it can be difficult to distinguish different voices. Focus groups are not costly, unless participants get paid for their time and a venue needs to be paid for. Focus groups were not used in the present research because the author of the present thesis thought that it was more time efficient to take up an hour of each project team members' time in separate interviews, rather than gathering them all together to collect only one hour of data from them all. There were also logistical problems as it often proved difficult to get all project team members together for a design team meeting, so it may have been even more difficult to gather the relevant members together for a focus group.

Action research is described as "research designed not simply to know the world, but to enable change" (David and Sutton, 2004, p.357). This approach was created by Kurt Lewin in the 1940s to encourage social research to tackle social problems (Schwandt, 2001). Action research is user-oriented, aiming to ascertain peoples' perceptions of certain topics. This has risk attached to it, as the results of the research are ever changing as the co-researchers involved are unpredictable (Miller and Brewer, 2003). Lowe et al. (2003c) used action research, collecting data through: design team meetings, interviews, workshops, informal meetings, demonstrations, e-mail exchanges and working papers. Action research was seen by Lowe et al. (Ibid) as being the only way to: engage stakeholders in the enhanced energy standard set by the project; document and evaluate the process; and provide an arena for the researchers to utilise their knowledge and skills. Action research was not used in the present research as it is a very involved method and would have needed to be initiated from the very beginning of the project, which was not possible. It also requires considerable time, resources, knowledge and expertise in the area. The author of the present thesis was not in a position to enforce such a method and was keen to observe the design process as it was, rather than how it could be.

Life-cycle analysis is used to assess the environmental impact of a product over its life cycle: production to disposal (Smith and Whitelegg, 1997). Environmental impacts are looked at in relation to resources, human health and ecological consequences (The University of Bolton, 2005). Bogenstätter (2000) evaluated the life-cycle costing of 2900 buildings in Germany and Morel et al. (2001) compared the embodied energy in three domestic dwellings. Fay et al. (2000) compared the predicted life-cycle energy of two case-study houses, as outlined in p.39. Life-cycle analysis was not used in the present research as to provide an accurate overview, a great deal of information about material performance, costs and construction energy is needed that was not available to the author of the present thesis at the time the research was conducted. This information is often not available as manufactures rarely provide this sort of detail about products and estimates are complex and difficult to calculate.

Multi-criteria decision analysis (MCDA) is used to appraise design options and has a particular relevance to problems that have an impact on the environment (ODPM, 2000). MCDA provides "support for multivariate decision making, where variables can be ranked, weighted, assigned importance with adjustable relevant ranges" (The Centre for Human Computer Interaction Design, 2006). Multi-criteria decision analysis was used by Balcomb et al. (2000) and Ding (2005) to evaluate the environmental performance of building designs prior to construction. Computer programmes were then used for selection of buildings designs. MCDA was not used in the present research as the author of the present thesis was not involved in the very early design stages and had little influence over the methods and procedures being used. The method would also have meant that the author of the present thesis was unable to capture the 'natural' process of decision making by the project team.

4.5 Chapter summary

This chapter has described the methods used in the three methodologies underpinning the present research. These have been designed to fulfil the research objectives and were informed by previous literature on the subject. The three methodologies correspond with the following three results chapters of the present thesis.

- Chapter 5, *A design process: incorporating the high environmental standard*
- Chapter 6, *Design decisions: exploring decisions that affect the environmental impact of houses*
- Chapter 7, *Professionals in the design process: their perspective*

5. A Design Process: incorporating the high environmental standard

The design process consists of the procedures needed to design and construct a building, which makes it key to any project. The design process for each project is unique, but there are a number of common elements that apply to all. Environmental considerations, such as energy efficiency, are generally not considered within these common elements, even though they are becoming an increasingly important aspect of construction (Sustainable Development Commission, 2006). This chapter highlights where environmental considerations should be addressed in relation to the common elements of the design process. The aim is to demonstrate how these considerations can be incorporated into a design process model that could form guidance to enable the delivery of low-energy housing. The design process has been researched and documented in academic and non-academic publications, as reviewed in Chapter 2, p.25. The differences between the case-study design process (detailed in Chapter 3, p.49) and one generic model of the design process, the Royal Institute of British Architect's (RIBA) *Plan of Work* (Phillips, 2000), are discussed in this chapter to enable comparisons to be made that could form guidance for the development of low-energy housing.

Six factors that were identified as being key to the incorporation of the high environmental standard into the design process at the case-study development are discussed in this chapter. These factors were identified from template analysis undertaken on both the design team meeting data and the documents distributed at these meetings. The methods used to analyse these data were described in Chapter 4 (section 4.2, p.60) and the methodology used to combine these methods was described in section 4.3.1 (p.73). The predefined terms used to initiate template analysis and identify the six factors for discussion were developed from creating and analysing a matrix of issues about the design process referred to by previous literature. These were grouped into broader themes for initial analysis and included: communication, contracts, cost, design process, design team and problems/delays. The template was developed and the data were analysed over several iterations described in Chapter 4 (section 4.2.3, p. 67). The final template used to code the data is presented in Appendix D, p.271. This shows all the lower-order codes for each of the factors which aided analysis and discussion. This process identified the six factors that were key to the incorporation of the high environmental standard into the design process discussed in this chapter. The selection of data for each of these factors was heavily influenced by the need to fulfil the research objectives, outlined in Chapter 1 (section 1.1, p.11). The following operational definition was used to select only those factors that were of relevance to the present research:

> Elements of the design process that relate to tasks or actions that contribute to increasing the environmental standard achieved by the house designs. These can form part of the design process outlined in the *Plan of Work* (RIBA, 1998), but have to be additional elements that will enhance the design process to enable the high environmental standard to be achieved, or form a new element of an existing design process stage.

The factors identified from the template analysis were:

- Principles
- Project team
- Tendering
- Procurement
- Contracts
- Cost

These factors differ slightly from the predefined terms developed from the previous literature, although all topics, apart from problems/delays, were included in the final template and therefore in the six factors above.

This chapter outlines the base-line design process used for comparison, the RIBA *Plan of Work,* and then discusses in turn the six factors identified by template analysis of data from the case-study development. A graphical representation showing the frequency with which each factor was mentioned in the design team meetings and documents is also presented and discussed. These were the result of content analysis of the data and are followed by a comparison to the stages of the *Plan of Work.* Each factor is then discussed in relation to previous research and then a short conclusion is provided.

Quotes presented in this chapter, unless otherwise stated, are taken from the author of the present thesis's field notes made during design team meetings.

5.1 Base-line design process

As outlined in Chapter 2 (section 2.3, p.33) there are many models of the design process. These serve various purposes and apply to different building projects. None of these, however, specifically relates to housing developments. Therefore the RIBA's *Plan of Work* (Phillips, 2000) was used as the generic or 'base-line' design process for comparison with the design process for low-energy housing observed at the case-study development. The RIBA *Plan of Work* was selected because: it was established over 40 years ago in the form of the *Plan of Work for Design Team Operation* (RIBA, 1963); is widely used by those in the building industry (RIBA, 1998); and is referred to by several of the publications included in the literature review (e.g. Building and Social Housing Foundation, 2002; Lawson, 2004; Mackinder and Marvin, 1982). The *Plan of Work* is used when the architect is appointed at an early stage of a design project and where members of the architectural practice led the design team (RIBA, 1998), which was the situation at the case-study development.

The current RIBA *Plan of Work* (1998), which will be used for comparison, consists of 11 stages (A-L, with no stage I):

A. Appraisal

A feasibility study is carried out, along with a review of design and construction techniques and their specific cost implications.

B. Strategic Brief

The strategic brief for the project is prepared by the client and given to the architect.

C. Outline Proposals

The strategic brief is developed into the design brief for the project. Outline proposals are prepared and approved along with costs for construction. A planning supervisor is consulted when necessary.

D. Detailed Proposals

The design brief is finalised and detailed proposals are created from the outline proposals and approved by the client. Cost estimates are prepared, statutory authorities are consulted and a full planning permission application is developed and submitted.

E. Final Proposals

Final proposals are created from the detailed proposals. Cost estimates are revised and approval is sought from the client on construction type, material quality and the revised cost estimate. Statutory authorities are consulted on the proposed final designs and consequences of revised cost and programme are considered.

F. Production Information

Production information is prepared for the tendering process, which can include schedules of rates, quantities, schedules of work and revised costs. Building Regulation submissions are prepared as well as production information required for construction purposes.

G. Tender Documents

Tender documents are prepared and collated to allow tenders to be obtained. Pre-tender costs are then prepared and the planning supervisor is consulted.

H. Tender Action

Reports on tenders are negotiated and production information is revised if tender sums have changed.

J. Mobilisation

Production information is provided for the building contract and for construction.

K. Construction to Practical Completion

Visits to site are conducted with further information provided for construction. Design information is reviewed for contractors and drawings showing drainage and other information for health and safety are provided. Operation and maintenance advice for the building is given.

L. After Practical Completion

Defects are identified and a final inspection is undertaken and final accounts are settled.

Stages C (Outline Proposals) to J (Mobilisation) are considered here as these are the stages of the case-study design process that were monitored. The RIBA's *Plan of Work* (Ibid) does not contain any measures to encourage or guide sustainable development or to mitigate the effects of climate change, but this is not its intention as it does not relate to performance. It is used here as a starting point to gather information that could form guidance for project team members wanting to achieve low-energy housing. The RIBA have published two guides entitled *Low Carbon Design Tools* (RIBA, 2007b) and *Low Carbon Standards* (RIBA, 2007c) which list design tools and standards that can be used to design low-carbon buildings. These were, however, published very near the end of the present research and only list design tools and standards that could be used and do not relate to the design process. This base-line design process is compared to the factors identified by template analysis in the following sections to start the process of developing a new model that could be used to form guidance to help achieve low-energy housing.

5.2 Principles

Setting overarching principles for a project provides guidance on the direction in which the project should proceed and enables objectives to be set, which the project seeks to achieve. In the case-study development the principles were set out during the design team meetings and recorded in the documents distributed at these meetings. These mechanisms for setting principles are discussed in this section, along with a discussion of the restating and revisiting of the principles. The section concludes by focusing on how this process differs from that presented in the RIBA *Plan of Work* and by referring to literature reviewed that addresses principles.

5.2.1 Setting principles

Principles were set in the first eight design team meetings at the case-study development, these are detailed on p.91. These spanned five months from 8th April to 25th August, 2005. The frequency with which these principles were referred to in the design team meetings is shown in Figure 5.1, which highlights a period between meetings 1 (Introduction to process) and 8 (Phase 1 master plan), when the principles for the project were set and communicated to the project team. Table 3.1 (section 3.2.1, p.51) shows the design team meetings and their corresponding numbers referred to in this chapter.

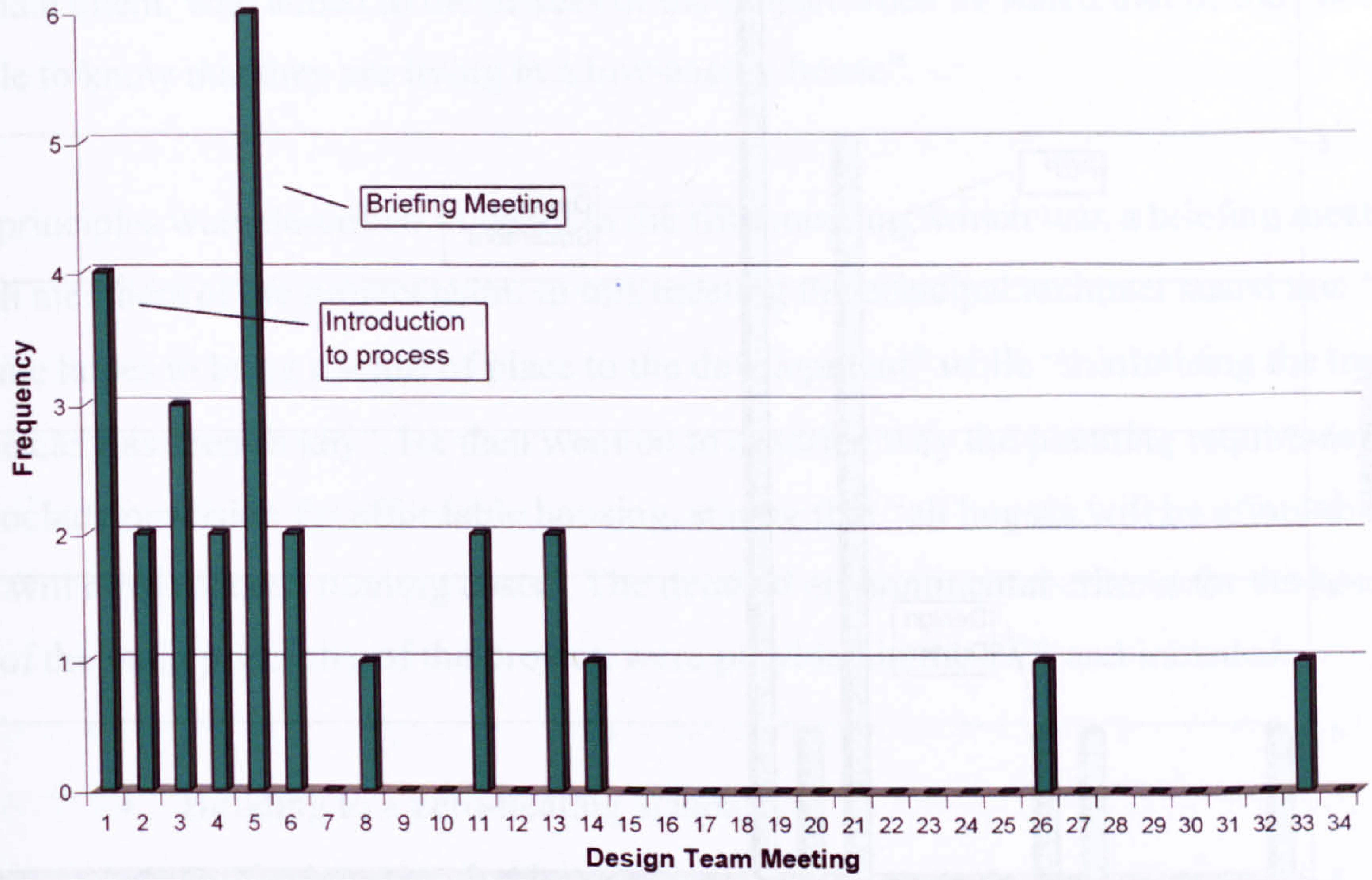


Figure 5.1: Frequency with which principles were referred to in design team meetings

The frequency with which the principles were referred to in the documents distributed throughout the design process is shown in Figure 5.2. This illustrates that two documents were prominent in setting principles, the *Project Execution Plan* (PEP) and the *Design Brief.* Table 3.2 (section 3.2.2, p.53) shows the documents distributed at design team meetings, along with their corresponding numbers.

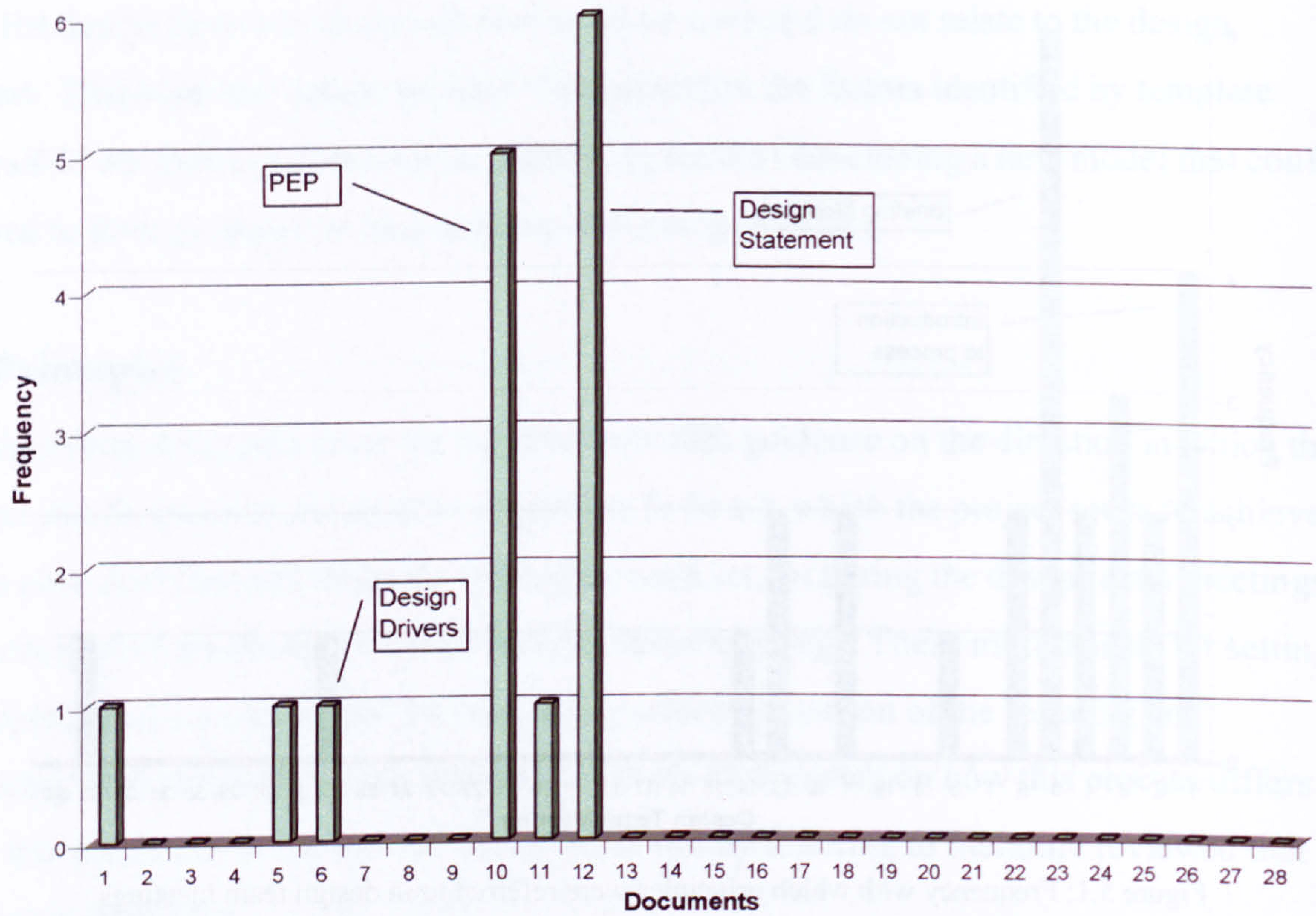


Figure 5.2: Frequency with which principles were referred to in documents distributed at design team meetings

Principles formed a significant part of the first design team meeting, with the project manager commenting that the project drivers, which were also referred as the principles of the project, needed to be "distributed and revisited, with comments made and a final version agreed" and that they needed to be "defined before the start of stage 1 of the process". These principles were to be communicated to the entire project team as well as disseminated to the board of directors at the case-study development. It was stated that the PEP, distributed in Meeting 5 (Briefing), was going to be the mechanism for communication of these principles to all parties.

The second design team meeting was the first time that the content of the principles was discussed. The main client stated that "planning constraints and issues to be added to key design drivers will include EcoHomes". This was expanded upon in the third meeting when the second client stated that "energy use needs to be reduced as much as possible within these houses". The fourth meeting established that the drivers would need to be agreed by the main client, who added to the drivers of the project when he stated that he did "not want people to know that they are living in a low-energy house".

The principles were described in detail in the fifth meeting, which was a briefing meeting for all members of the project team. In this meeting the principal architect stated that "the scheme hopes to bring a sense of place to the development" while "minimising the impact of the car was seen as key". He then went on to describe why the planning requirements did not include provision for affordable housing, stating that "all houses will be affordable as they will have reduced running costs". The detailed environmental criteria for the houses, one of the main principles of the project, were provided in the PEP and included:

- Building to a zero-heating standard.
- Achieving specific U-values:
    - 0.14 W/m^2K for masonry walls
    - 0.1 W/m^2K for light-weight timber frame
    - 0.1 W/m^2K for floors
    - 0.1 W/m^2K for roofs
    - 1.1 W/m^2K for window/door
- Providing solar hot water to all roofs that were south-facing or up to 25° off south.
- Installing rain water harvesting systems.
- Providing heating, when required, by ground source heat pumps.
- Using natural external materials.

These have been slightly revised as the environmental criteria presented in the PEP (SEV, 2005, p.5) had several errors; quoting the U-value units as $w/m^2C°$ and the masonry walls and light-weight timber frame U-values as 1.4 and 1.0 respectively.

The standards presented were set as planning conditions at the beginning of the design process and were much more stringent than both the current Building Regulations and the

EcoHomes excellent standard described in Chapter 1 (section 1.2, p.11). These standards would be approximately equivalent to level 5 of the Code for Sustainable Homes, also described in Chapter 1 and summarised in Table 1.1.

In meeting 5 the project manager made clear that "everybody needs an equal understanding of the scheme". He then went on to summarise the principles for the project as "exceptional houses, different houses and highly efficient housing". He also noted that the scheme needed to be commercially viable and that it needed to comply with the deed of variation and the planning conditions. In addition, he stated the "need to sell the properties and for them to be desirable as well as sustainable". He reaffirmed that "it would be good for people to be surprised at the sustainability of the houses", as suggested by the main client in the previous meeting. The second client was keen that people were aware of the "spaces in between too" and was concerned that "when input is made it needs to make sure that we don't move away from the design principles". This concern was also expressed by the project manager in the sixth meeting when he stated that the "drivers can't be changed".

The principles outlined in the design team meetings were brought together as Key Design Drivers in a memo (doc.6) distributed to the core design team. These were established as initial design drivers with scope to change through further discussion. It was during meeting 5, when the PEP (doc.10) and Design brief (doc.12) were distributed, that everyone in the project team was informed of the principles for the project. The principles were described throughout the PEP; in the preface and the project history. The document listed the following objectives and drivers, which were referred to as the project principles (SEV, 2005).

1. Exceptional housing – the development was to be somewhere people want to live. The site was to be designed to create a sense of place and minimise the impact of the car.
2. Different housing – the development was to comprise house types and styles that were not available elsewhere.

3. Highly energy-efficient housing – the development was to offer exceptionally low running costs to potential occupiers.
4. The scheme was to be commercially viable and make a return.
5. The scheme was to comply with the requirements of the deed of variation.
6. The scheme was to deliver the requirements of planning consent.

The principles were again outlined in the Design brief for the project, although these had a more design-focused bias as the document was created by the client and architect, without the other members of the design team. The principles were listed in the Design brief (JDA, undated) under three headings:

- Site concept
- Layout
- House specification

One principle stated in this document was not stated in any of the earlier meetings where principles were being set, or in other documents. This was in the house specification section, which stated that all "materials and labour should be sourced locally where possible" (Ibid).

5.2.2 Reinforcing and revisiting principles

Some of the principles set in the design team meetings and documents distributed at these meetings were re-stated during later design team meetings. Figure 5.1 shows a distinct gap between the first eight meetings when principles were set and meetings 11 (EcoHomes excellent) to 22 (Achieving cost certainty 2), when principles were revisited and reinforced. The principles were discussed generally, as well as with a focus on specific items.

The principles were especially reinforced in relation to the change in the environmental standard from zero-heating to EcoHomes excellent. The principal architect stated in meeting 11 that "the principles are still there, we will still look at the same elements for zero or excellent". This was just prior to the project manager saying that "a different development with a better quality and a sense of community will all stay; the beliefs will be protected". The zero-heating standard meant that the houses would need to be designed and constructed in such a way that they did not need to use any energy for heating, whereas EcoHomes excellent covered many areas of the development, as outlined in Chapter 1 (section 1.2, p.11). EcoHomes addresses issues other than energy use and due to this, the reduction of energy use in the EcoHomes standard is less stringent than that of the zero-heating standard, which would reduce the energy for heating to zero. The main client stated in meeting 13 (Risk workshop) that EcoHomes excellent was a starting point for the development. This reassurance was stated again in more general terms in meeting 14 (Programme), when the project manager assured the project team that "the principles will not be destroyed, they are solid and are not going anywhere". He also reinforced the importance of the principles by saying that "the process has been based around the principles".

The fact that the development needed to deliver "commercial high-quality, affordable housing" was also restated by the main client in meeting 13. This was followed by the project team being reminded that "working as a team is seen as very important". Towards the end of the design process (meeting 26), the project manager declared that there was a "distinct need to make a profit" and in meeting 33 (Actions to get on site) went on to say that "if we go back to the drivers, we want to make an impact". This was a reference to achieving something different in the design of the houses compared to conventional developments.

5.2.3 Conclusion

This process of setting and revisiting principles is not mentioned in the RIBA *Plan of Work*. If principles were included, they would form part of stages B (Strategic Brief) and C (Outline Proposals), where the strategic or design brief for the project is created, discussed and finalised. The *Plan of Work* does suggest that the outline, detailed and final proposals are approved by the client. This, however, puts all the emphasis on the client to make sure that these principles are included in the proposals. It would be more effective to make everyone jointly responsible for the principles, as observed in the case-study design process. In previous literature, clear principles have been identified as an important element of low-energy building design. Pearl (2004) stated that "students and architects must return to the modernist bio-climatic principles" (p.32). Hayter and Torcellini (2000) identified principles as important and assigned the good building performance of a case-study project to that fact that "owners of the project made a strong commitment to sustainable design principles" (p.5). Finally, Reed and Gordon (2000) stated that "ecological design objectives are not identified, developed and incorporated early enough in the planning process" (p.326).

5.3 Project team

The project team of any design project is crucial to that project becoming realised. The way this team is formed and how it works can have a positive or detrimental effect on the success of the project, as it is dictated by their actions. In the case-study development, the project team was established fairly early in the design process, with meeting 5 (Briefing) being the first time all members met. The workings of this project team, in terms of the partnering arrangement used, communication within the team, the relationships formed, conflicts within the team and roles, are discussed in this section. The section then concludes by focusing on how this process differs from that outlined in the RIBA *Plan of Work* and refers to examples from previous research.

Aspects of the project team were referred to throughout the series of design team meetings, shown in Figure 5.3. A concentrated period can be seen towards the beginning of the process; meetings 1 (Introduction to process) to 5, when the project team was formed. Figure 5.4 shows when the project team was referred to in documents distributed at design team meetings.

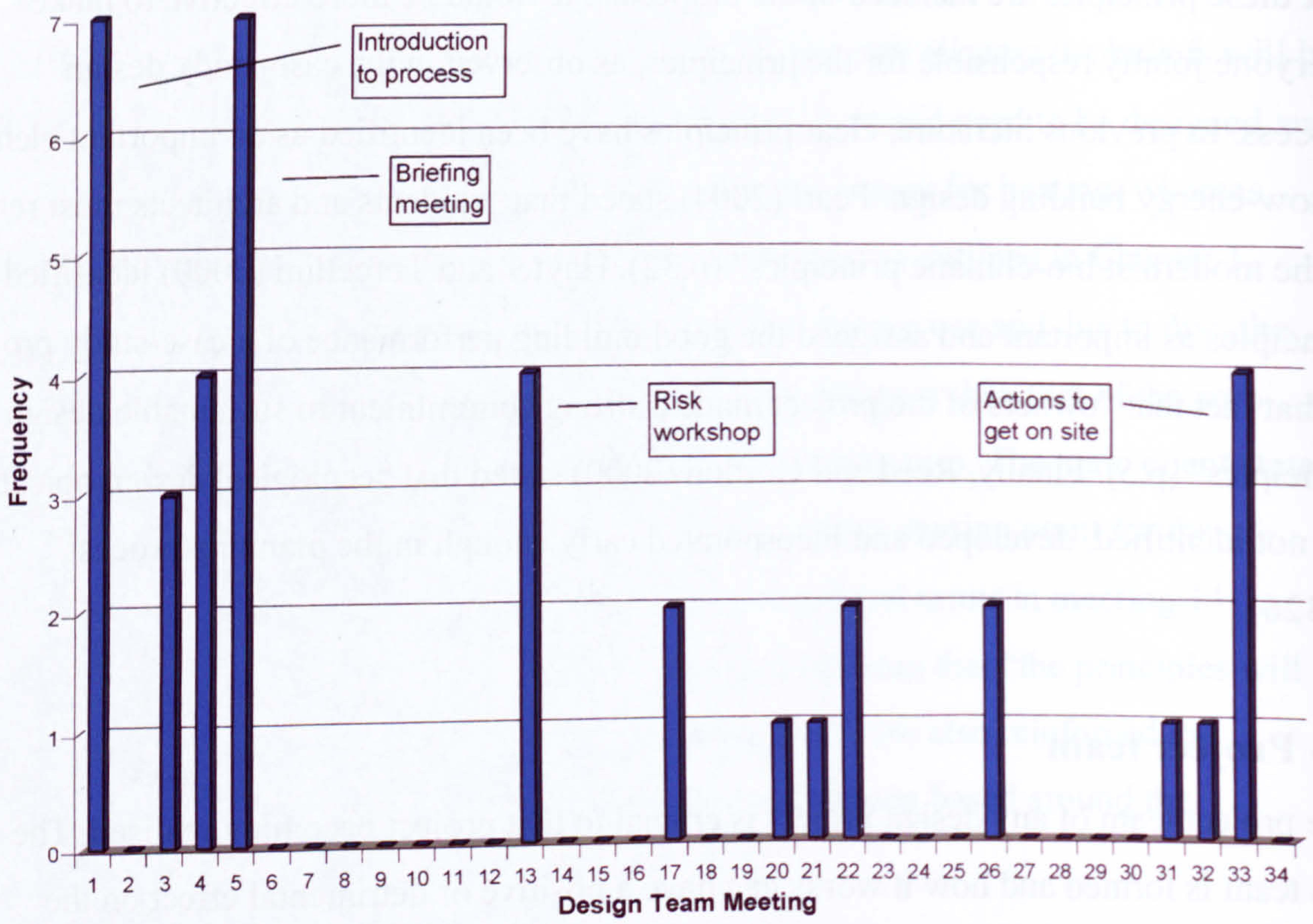


Figure 5.3: Frequency with which aspects of the project team were referred to in design team meetings

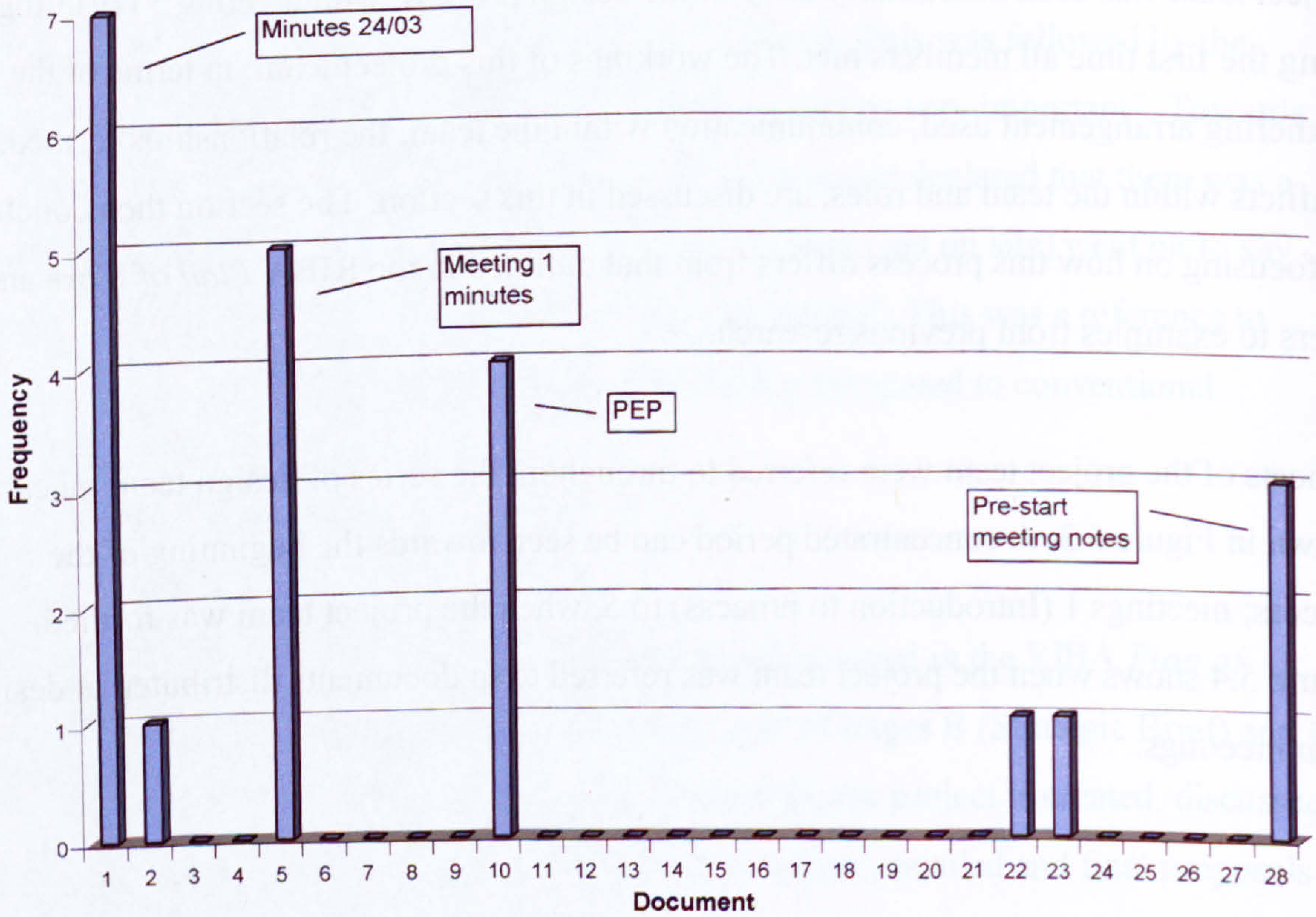


Figure 5.4: Frequency with which aspects of the project team were referred to in the documents

5.3.1 Partnering arrangements

Partnering arrangements are established to make sure that all parties involved in the design process are appropriately represented. Partnering is defined as "an agreed method of working together as an integrated and co-ordinated team to achieve common objectives and shared benefits" (Constructing Excellence, 2006). Partnering arrangements were discussed from the outset of the case-study design process. In the first design team meeting the project manager stated that "partnering principles need to be understood and discussed". Partnering was not mentioned again until the Risk workshop (meeting 13) by the representative of the East Midlands Development Agency (EMDA) who said that "partnering needs to be signed up to and changes agreed". In meeting 17 (EcoHomes, procurement and tendering), the contractor mentioned partnering for the final time, when he said that "partnering means transparency and the relationship is therefore better as the project manager gets to have all the headaches". Partnering was also outlined in document 1 (Minutes 24/03/05) where it was stated that "all parties need to think through the principles of a partnering arrangement for discussion". Document 5 (Meeting 1 minutes) went on to state that the project team could "agree partnering in principle, but could not be fixed at present". The partnering arrangements were not established in the early stages of the design process, as there was still a possibility that the project team could change. This was due to the project manager and main client perceiving a lack of commitment from the contractor.

5.3.2 Communication

Communication within the design process tends to be complex (Dainty, Moore and Murray, 2006), as many of the tasks involve multidisciplinary skills and therefore expertise from several members of the project team. The communication network for the case study development was outlined in the Management and Communication Network (doc. 2) presented in the first meeting. This was presented to the project team in the PEP (doc.10) and was discussed in meeting 5. The Management and Communication Network is outlined in Figure 5.5 and shows that the client was only supposed to communicate with the sales and marketing team and the board of directors. The client was also shown as having strong links with the project manager who was at the hub of the design process as almost every party was shown to communicate with him. The Management and Communication Network was reviewed by all present at the briefing meeting and this version was agreed in principle, although it was made clear that at this stage in the process these communication channels were not fixed. In the pre-start meeting notes (doc.28) communication was mentioned again. It was reiterated that "all information to the design team/client comes via the project manager" and that "all information back to the project team should go via the contractor", which was not shown in the diagram. The communication network changed over time, with the design team often being in direct communication with the construction team and the author of the present thesis communicating with most parties directly. The boundaries of communication outlined in Figure 5.5 were put in place to enable the project manager to be in control and to reduce the potential for contradictory messages from different sources.

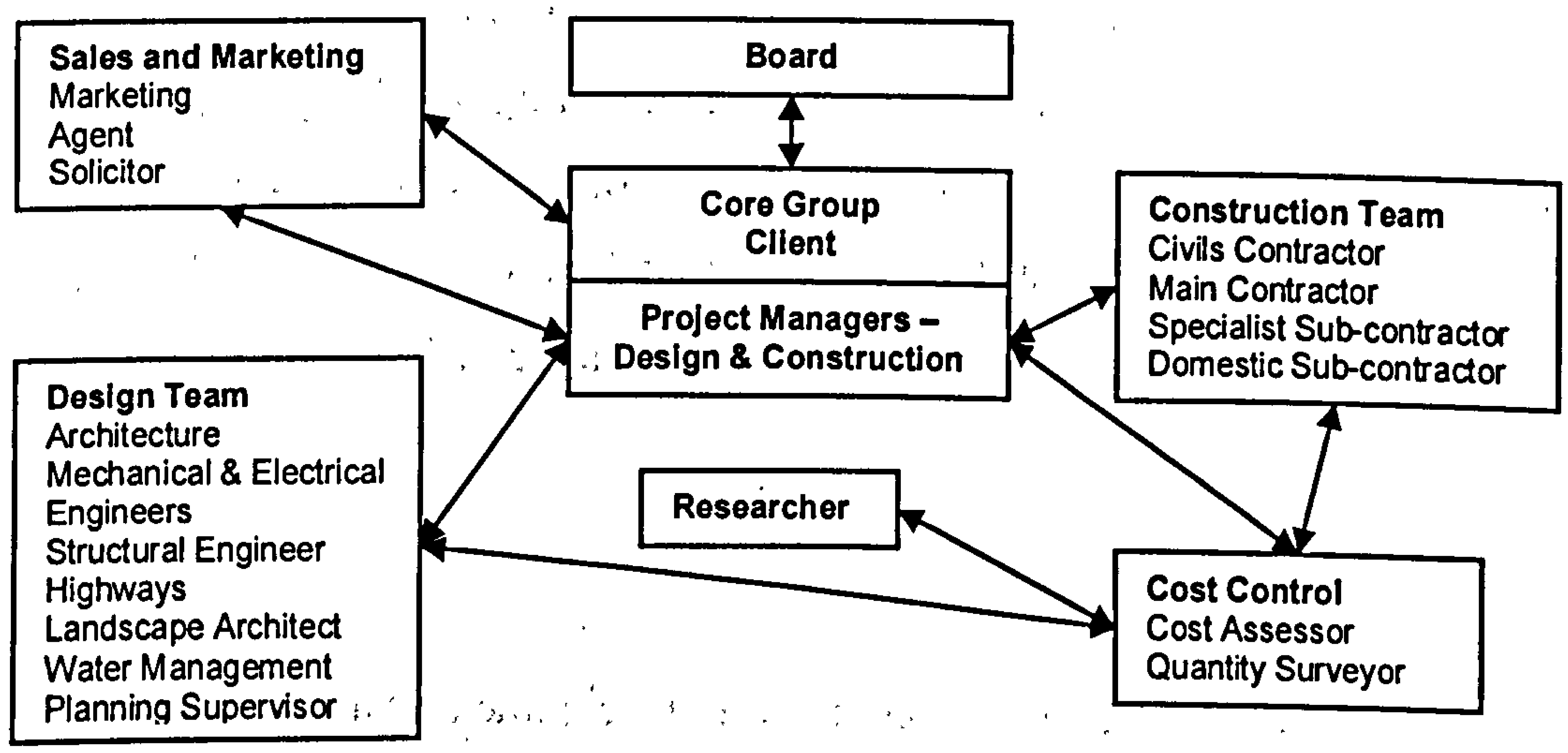


Figure 5.5: Management and Communication Network, as outlined in the PEP

5.3.3 Relationships

It was evident throughout the design process that working as a team was a very important aspect of the project. This was suggested in design team meeting 5 by the project manager who stated that "everybody needs an equal understanding of the scheme", with the main client seeing this meeting as a chance to "build the team and introduce everyone". He then went on to state that "everyone should work as a team and any thoughts need to be stated and inputted". Prior to this meeting the core design team was formed, and was defined in meeting 4 (PEP) as including the client, the architect and the project manager. In this meeting, the principal architect established that the core design team would have information fed to them from the project team, but the core design team would make the decisions. However, in meeting 22 (Achieving cost certainty 2), the project manager stated that the "whole design team will need to discuss this and thrash through all decisions". Thus, although it was stated early on that the core design team would make the decisions, towards the end of the design process many more parties input was necessary to make decisions.

The need to "work in everyone's interest" was stated in meeting 17 by the contractor, who said that "this is a far better way of working than trying to get one over on others". Transparency was also mentioned in this and various other meetings, including by the project manager in meeting 22. The final mention of working as a team was in meeting 26 (Ground works), when the project manager stated that he worked in the same way as the architect and the contractor, this way of working was developed through previous working relationships (on an earlier developments).

5.3.4 Conflicts

The subject of conflicts within the design process was first raised in meeting 3 (Updated programme), where the project manager stated that "all conflicts will be resolved in these meetings, with views challenged until a decision is made". Concern about such conflicts were also revealed by the project manager when he said that "there were worries that this process may be taken over by certain parties and that they would become too involved", referring to the contractor. In meeting 4, the main client echoed this by saying that "any undue influence will be stopped as soon as possible". Conflict did not actually arise until meeting 20 (Infrastructure), when the project manager expressed frustration with both the contractor and the M&E (mechanical and electrical) consultant for delays in the process. This frustration was reiterated in meeting 26 when the project manager was "worried about the formation of the design team staying in place". This was in relation to a time constraint imposed by EMDA. These concerns were both raised in meetings that looked at the civil engineering work on the site, which, by its nature, involves several external actors (water companies, highways and planning). Towards the end of the design process, in the penultimate meeting, the project manager stated that he had to "force people into not delaying any more" and admitted that "we can bully our way to it, there are many hoops that need to be gone through, but there will be at any time". These conflicts appeared to affect the design process for a short while, with unease being observed by some parties involved, especially towards the end of the process before the contracts were in place. Once the contracts were in place and the project was being realised, these conflicts apparently disappeared as there seemed to be renewed confidence in the project.

5.3.5 Roles

The roles and involvement of the project team members varied a great deal. The role of each member of the project team is listed in Table 3.3 (section 3.2.3, p.54) and Appendix A (p.265) illustrates their individual involvement in the design process. Several of the project team members' roles meant that they only attended the briefing meeting. These were: safety officer; second and third contractors; quantity surveyor; and water consultant. The selling agent's role in the design process was towards the beginning and the principal architect and second client were also only involved in the early stages of the design process, with their last meetings being 11 and 16 respectively. The roles of the second safety officer and the two civil contractors meant that they only attended the very last design team meeting. The architect's role in the design process was the only one commented on specifically. In meeting 31 (Progress update) the project manager stated that the architect "is now out of the loop on this". He then added that "he has done a stunning job to get us to this stage, but we need to get on top of the costs". In the following meeting the project manager said that challenging the architect on "all aspects of the houses is reducing the aesthetics of the houses" and went on to say that they had lost their "wow impact" because of this. This was followed by a similar comment in meeting 33 (Actions to get on site), where the project manager stated that the "designs are now weaker and slightly less what the architect would like, less wow, but more accessible to the masses".

5.3.6 Conclusion

The project team was a very important part of the case-study design process, but it was not mentioned in the *Plan of Work*, although individual members of the team were. Team formation, sharing of principles, establishing working relationships and communication appeared to be beneficial in the case-study development and are likely to be beneficial in other instances. It was noted by the contractor in meeting 17 that working in everyone's interest was "a far better way of working than trying to get one over on others", which was the implied norm when the project manager stated "this is not the case here". Partnering, transparency and trust at the case-study development appeared to be the most important aspects of the design process. To enable a successful project, it was inferred that these needed to be established at the beginning. The experience of the case-study development indicates that the working of the project team is a very important part of the design process, with partnering being a part of this. Partnering would need to be incorporated between stage B (Strategic Brief) and stage C (Outline Proposals) of the *Plan of Work*. Partnering is referred to by the majority of reviewed publications that investigated the design process. Lowe et al. (2003c) stated that the "partnering approach was perhaps the most important determinant of the design process" (p.x). In Gangemi et al. (2000) it was explained that "co-operation amongst the various members of the design team is considered of fundamental importance for the project's success" (p.283) and Torcellini et al. (2005) saw assembling a project team committed to low-energy building as the first lesson from the design process.

5.4 Tendering

Tendering in the design process is the action of obtaining a formally agreed price for goods and services. The process involves members of the project team putting together packages of relevant information so that sub-contractors can offer a price for doing a certain job or supplying certain materials or products (Phillips, 2000). The tendering process is very important in the design process as the characteristics of the houses are dependent on the materials and products used and the quality of construction. In the case-study development, tendering was referred to most frequently in the middle of the design process. This can be seen in Figure 5.6, where tendering is mentioned from meeting 14 (Programme) to meeting 29 (Finance), with a spike at meeting 17 (EcoHomes, procurement and tendering). The tendering process was not alluded to in the documents distributed at the design team meetings.

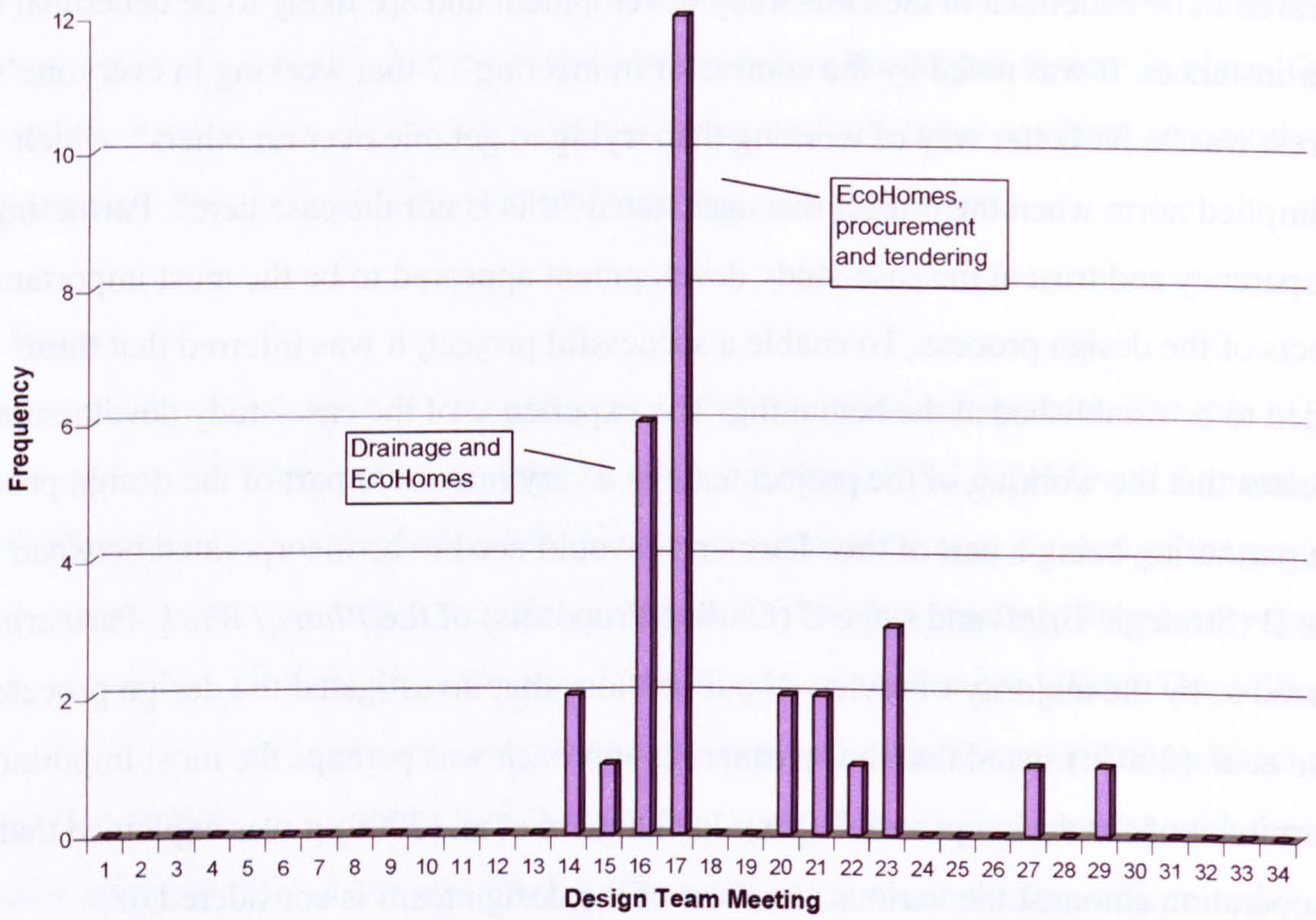


Figure 5.6: Frequency with which tendering was referred to within the design team meetings

Discussion of the tendering process started in meeting 14 when the project manager stated that the supply chain needed to be reviewed. This involved establishing the companies that were usually asked to tender as well as any additional suggestions by the client. In meeting 16 (Drainage and EcoHomes) the main client stated that he was keen for these to be local companies. The project manager stated that the contractor would do the "leg work" for this process.

Bills of quantity were prepared by the contractor and consisted of a list of work that needed to be undertaken, with a brief description for each task. The extent of each task is established so that the work can then go out to tender. In meeting 14 the project manager expressed a need for the bills of quantity to be prepared. These were then put together by the contractor prior to the tender packages being created. These bills of quantity were reviewed in meeting 17 by the project manager, who stated that the rates quoted as estimates were "not rates for house building" and that they were over £200 per square metre more than the target build cost. The project manager did, however, state that he was not too worried as there was some guess work involved, with the contractor saying that the costs "will only go down when prices become clearer".

Tendering packages were put together by the contractor after meeting 16, when the project manager stated that "tender packages need to be sent out". These contained a covering letter, extracts from the specification, and all standard drawings of the relevant house types. The project manager stated that there were "no whistles; the packages are normal like conventional house builders would use. This will keep prices down with these sub-contractors, as they are likely to add premiums if we point out that this is something different".

The tender packages were returned prior to meeting 20 (Infrastructure), when the project manager assessed them to understand them and compared them with the budget to see if value engineering was needed. The project manager then stated that the companies who submitted the best three prices were to be asked for more detail, as well as the benefits that may come with their service. In meeting 21 (Achieving cost certainty 1) the contractor stated the need for a series of meetings with potential sub-contractors to go through the caveats in the tender packages returned and to further specify prices. In meeting 22 (Achieving cost certainty 2) the contractor stated that he was "getting prices in from other suppliers if I was not happy with the original quotes". In the following meeting, 23 (Achieving cost certainty 3), the project manager echoed this by saying that "it's about paying the right money for what you want". As part of the tendering process the contractor made sure that some elements, such as brick laying, were quoted per house rather than per hour. This was explained in meeting 27 (Review of last 3 meetings) and meant that cost certainty was easier to reach.

The bills of quantity were scrutinised by the project manager prior to meeting 29, when he stated that the "contractor was prepared to go to contract with the Figures reached". This was the last time that tendering was referred during the design team meetings, which signalled the end of the tendering period.

The tendering process in the *Plan of Work* is covered by stages F (Production information), G (Tender documents) and H (Tender action), which occur midway through the design process. The process observed at the case-study development was very similar to that outlined in the RIBA *Plan of Work,* but there were a few subtle differences that proved to be very important to the incorporation of the high environmental standard. One of these was that the client at the case-study development had input regarding which companies the packages were sent to, with a preference for local companies, in order to reduce the environmental impact of transportation. Another difference was seen in the tendering process, with some company representatives being met so that detailed of the quotes could be further specified. Other companies were approached if the figures returned were not seen as competitive and there were also some items that were tendered directly. These measures are especially applicable to low-energy projects as risk premiums are often added by the contractor and sub-contractors, but with reassurance and explanation contractors' concerns seem to be able to be allayed.

5.5 Procurement

Procurement is the process of obtaining materials, products and services for a building project. These are procured from sub-contractors who have returned offers to tender. The selection of sub-contracts is often done by cost alone with the lowest tendering bid selected. In the case-study development this was not the case and many other factors were taken into account alongside cost. These included: locality of the suppliers; materials' source; and perceived quality of workmanship. The issues associated with the procurement process are discussed in this section and relate to the project team's approach towards procurement, the supply chain, sub-contractors and materials.

5.5.1 Approach

Procurement at the case-study development was considered from the very first meeting, which can be seen in Figure 5.7. In this meeting it was stated that procurement would be a busy and time consuming stage of the design process and the project manager argued that it was necessary to prepare so that it could be "hit with a flying start". Figure 5.7 shows that procurement was referred to throughout the design process, from meetings 1 (Introduction to process) to 30 (Resolving issues to get to construction), but discussion was concentrated in the middle stage, between meetings 9 (Surfaces and finishes) and 17 (EcoHomes, procurement and tendering). Procurement was revisited towards the end of the design process as the project got closer to construction; meetings 29 (Finance) and 30.

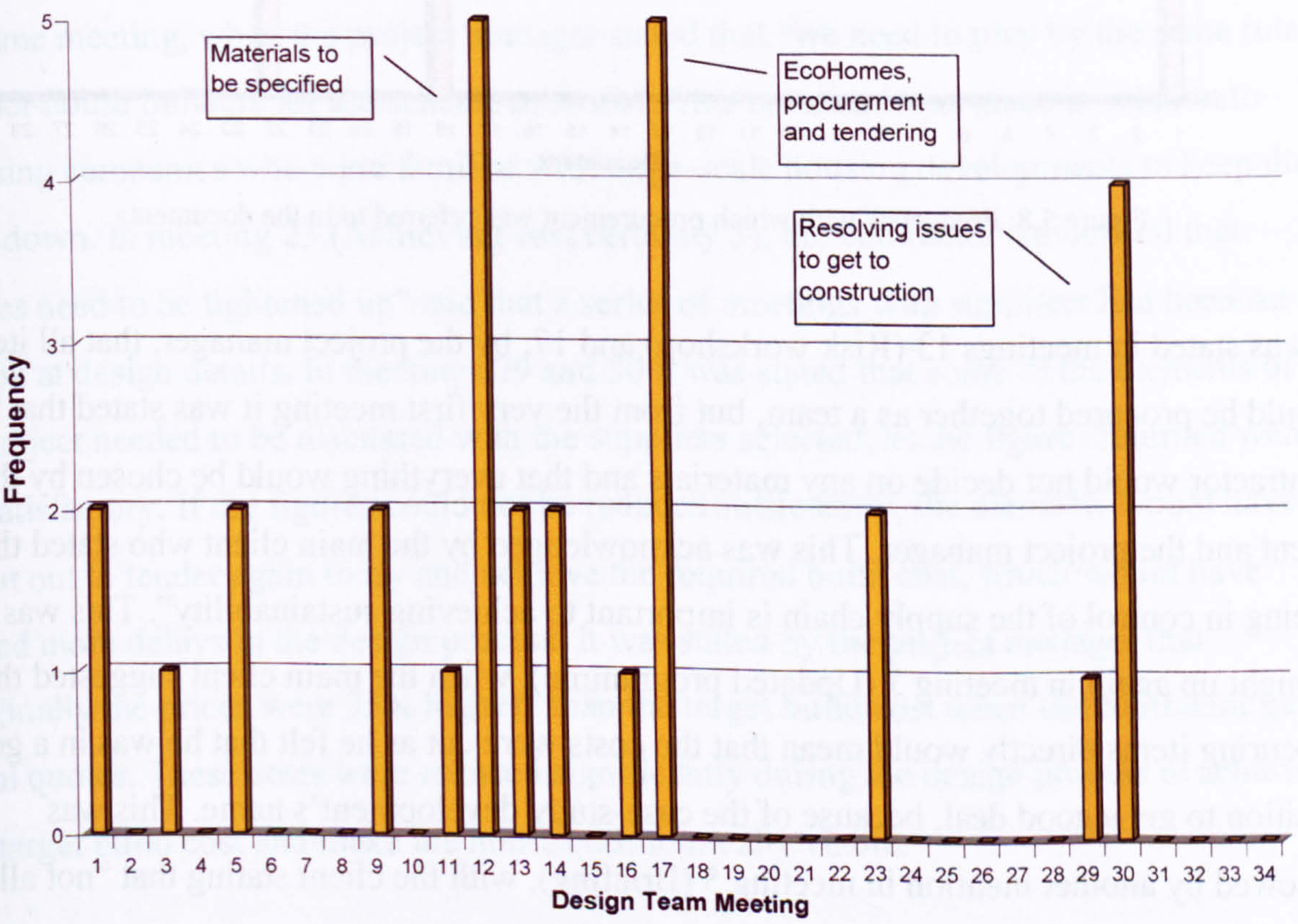


Figure 5.7: Frequency with which procurement was referred to within the design team meetings

Figure 5.8 outlines when procurement was referred to in documents distributed during the design team meetings. It shows that it was only referred to three times, which were spread throughout the process.

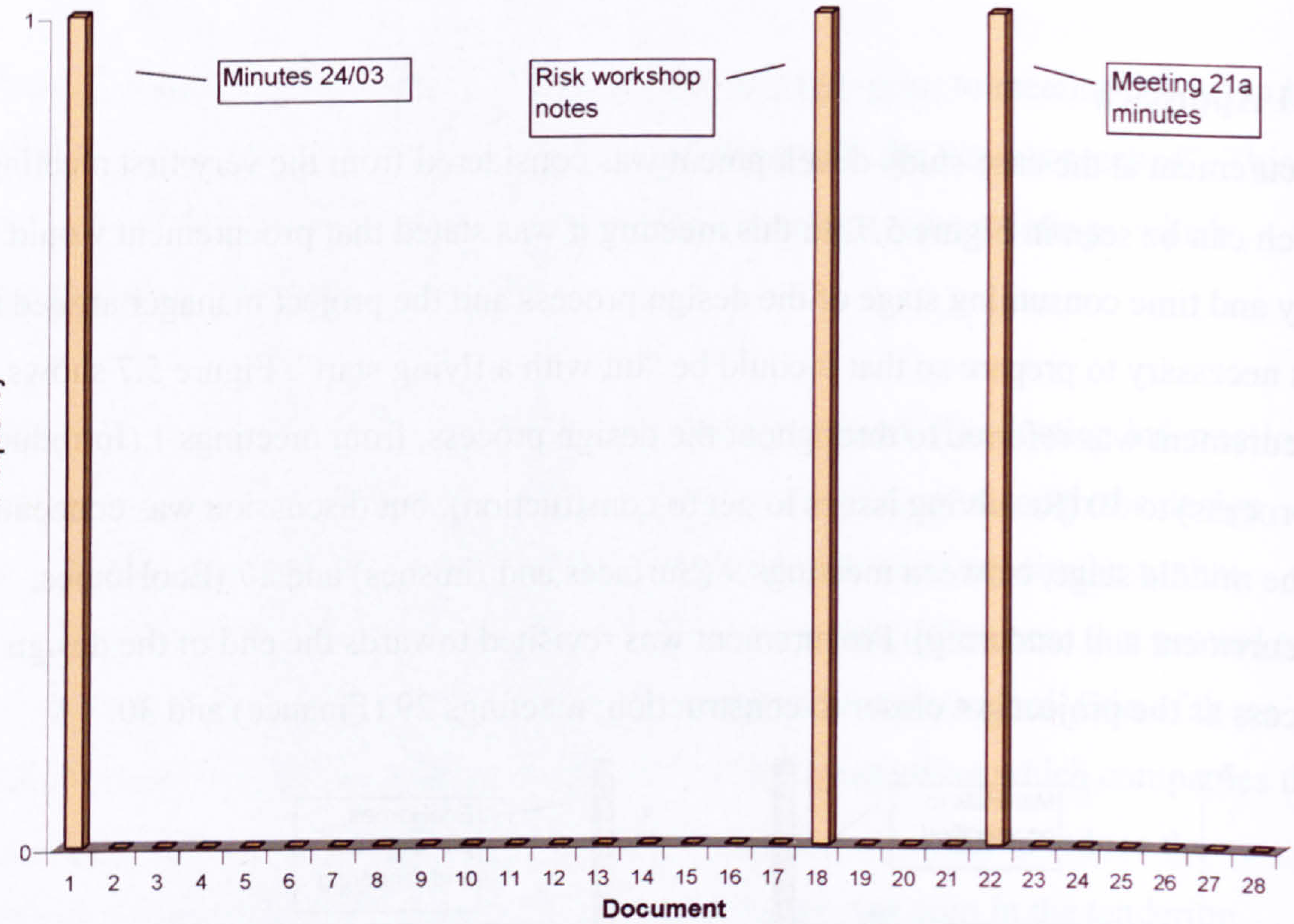


Figure 5.8: Frequency with which procurement was referred to in the documents

It was stated in meetings 13 (Risk workshop) and 17, by the project manager, that all items would be procured together as a team, but from the very first meeting it was stated that the contractor would not decide on any materials and that everything would be chosen by the client and the project manager. This was acknowledged by the main client who stated that "being in control of the supply chain is important to achieving sustainability". This was brought up again in meeting 3 (Updated programme), when the main client suggested that procuring items directly would mean that the costs were cut as he felt that he was in a good position to get a good deal, because of the case-study development's name. This was followed by another mention in meeting 5 (Briefing), with the client stating that "not all suppliers will be procured through the main contractor". The turning point in this attitude towards procurement came in meeting 12 (Specification of materials), where the project manager said, in relation to procurement, that "information will be taken as it comes and then will be discussed with the client". This was opposed to the earlier suggestion that materials would be procured directly by the client. This turn-around in attitudes came about when it was realised that procuring materials was a lengthy and complicated process and that the contractor was in the best position to do this.

The need to develop a strategy to procure supplies for the case-study development was noted by the project manager in the first document distributed at the design team meetings. The procurement strategy was then not mentioned again until meeting 17, when the project manager stated that the timber supplier, who the contractor had a partnering agreement with, would not be used if they would "not be competitive for these elements". It was also acknowledged in this meeting, by the project manager, that "we want to pay normal prices for materials, as we are building normal houses, nothing is out of the ordinary, just a little more thought and we will pay for this little extra thought". This point was reiterated later in the same meeting, when the project manager stated that "we need to play by the same rules as other house builders for the scheme to work". This comment was made in relation to choosing companies who were familiar with large-scale housing developments to keep the costs down. In meeting 23 (Achieving cost certainty 3), the contractor announced that "prices need to be tightened up" and that a series of meetings with suppliers had been set up to look at design details. In meetings 29 and 30 it was stated that some of the elements of the project needed to be discussed with the suppliers selected, as the figures returned were not satisfactory. If the figures could not be reduced sufficiently, the elements would have to be put out to tender again to try and achieve the required build cost, which would have caused more delays in the design process. It was stated by the project manager that "originally the prices were 35% higher" than the target build cost when the contractor gave initial quotes. These costs were reduced significantly during the design process to achieve that target build cost and make the houses economically viable.

5.5.2 Supply chain

It was in the middle stages of the design process that the supply chain was discussed. In meeting 13 it was established that the supply chain should be local and in meeting 14 (Programme) a list of local suppliers that could form the supply chain was discussed. The contractor reassured all parties involved that "there is a spread of geographical location and quality as we need to pitch it right, but we may not select the most competitive for various reasons, including quality". In meeting 23, the project manager noted that the length of the supply chain was to be reduced by going direct to certain manufacturers. It was also noted in document 18 (Risk workshop) that "all services and materials should be available from more than one source" to reduce risk and promote competition.

5.5.3 Sub-contractors

The choice of sub-contractors in the procurement process was key, as the various advantages and disadvantages of each needed to be weighed up and decisions made that helped the project meet its goals, which were not only financial. The existing relationships between the contractor and various sub-contractors meant that the contractor was keen to use these suppliers, but it was noted in meeting 12, by the project manager, that "choice will be performance related". In meeting 17, this situation was seen with a timber supplier who the contractor had a partnering agreement with and who was keen for the business, but the project manager made sure that the timber supplied would be "certificated to the same standard" outlined in the timber policy for the development. Towards the end of the design process, meeting 30, the sub-contractors, many of whom were holding orders for the project, were reportedly "unwilling to do any more work until they have some sort of guarantee". This concern was stated by the contractor who was also being "hassled for more money" as the prices from the sub-contractors had already been held for some time. This concern was highlighted again by the contractor, in the same meeting, when he said that "sub-contractors may have full orders by the time we go to them, if we don't go soon". This indicated that the contractor was very keen to go under contract because he was worried that if orders were not made at that point some of the suppliers would either increase the prices quoted or not be able to do the work, which would have delayed the process significantly.

5.5.4 Materials

Throughout the procurement process, materials for particular functions were needed. Choosing these materials and where they came from created a lot of discussion. This started in meeting 9 when the main client suggested a local manufacturer of paving, with the architect stating that "at the end of the day it will come down to cost". The main client was keen for the embodied energy of the materials to be considered. He explained that the local manufacturing plant had a much lower impact on the environment than others located further away as it "reuses heat from the drying room to cut gas use and costs by a significant amount". Meeting 12 brought a discussion of what 'local supplier' actually meant. The main client argued that local is the nearest supplier of the particular product. Some materials were substituted due to transport distance and expense. This happened with wall ties, in meeting 12, when it was argued by the architect that they should not be stainless steel because thermal bridging could occur. The nearest supplier of alternative fibre-glass ties was, however, stated as being Norway, so these were dismissed without further analysis. It was in meeting 12 that the specification of some materials was referred to for the first time, with the project manager saying that the block specification should come from the *Green Guide to Specification* (Anderson et al., 2002). This was also the case for the lintel specification, with the supplier of these to be chosen on the merits of their environmental policy, as there were no other criteria for comparison.

5.5.5 Conclusion

In the *Plan of Work*, the procurement process is covered under stages H (Tender action) and J (Mobilisation), which are both towards the very end of the design process. In the case-study development procurement was thought about from the very beginning of the observed process and was referred to at various stages. The procurement process was guided by various drivers that were essential to deliver the principles of the project. If these principles were not thought about during procurement and the contractor had been left to procure supplies without clear specifications, the environmental impact of the project would have been significantly increased. Sandahl et al. (1994) stated that "since energy-efficient systems are often more expensive on a first-cost basis, it is tempting for contractors or subcontractors to substitute less costly, less-efficient equipment" (p.16). Wilson et al. (1998) stated that the in the UK, the 'Design and Build' procurement approach meant that "primary design responsibility has been passed to the volume house builders, who are building to a price, within a minimum quality standard" (Ibid, p.2).

5.6 Contracts

Contracts form the legal base of any building project. The items present in the contract dictate the end product built, thus having a great impact on the success of the finished building. In the case-study development the contract was discussed during the design team meetings and its progress was detailed in the documents distributed. The contract document is discussed below in four sub-sections: time, elements of the contract, content, and the external actors involved in establishing the final document.

The contracts were referred to throughout the design team meetings, as shown in Figure 5.9. The diagram shows a peak towards the end of the process (meetings 29 to 34) when the contracts were established. Figure 5.10 shows a concentration of references to the contracts in documents 22 (Meeting 21a minutes), 23 (Meeting 22 minutes) and 24 (Meeting 23 minutes).

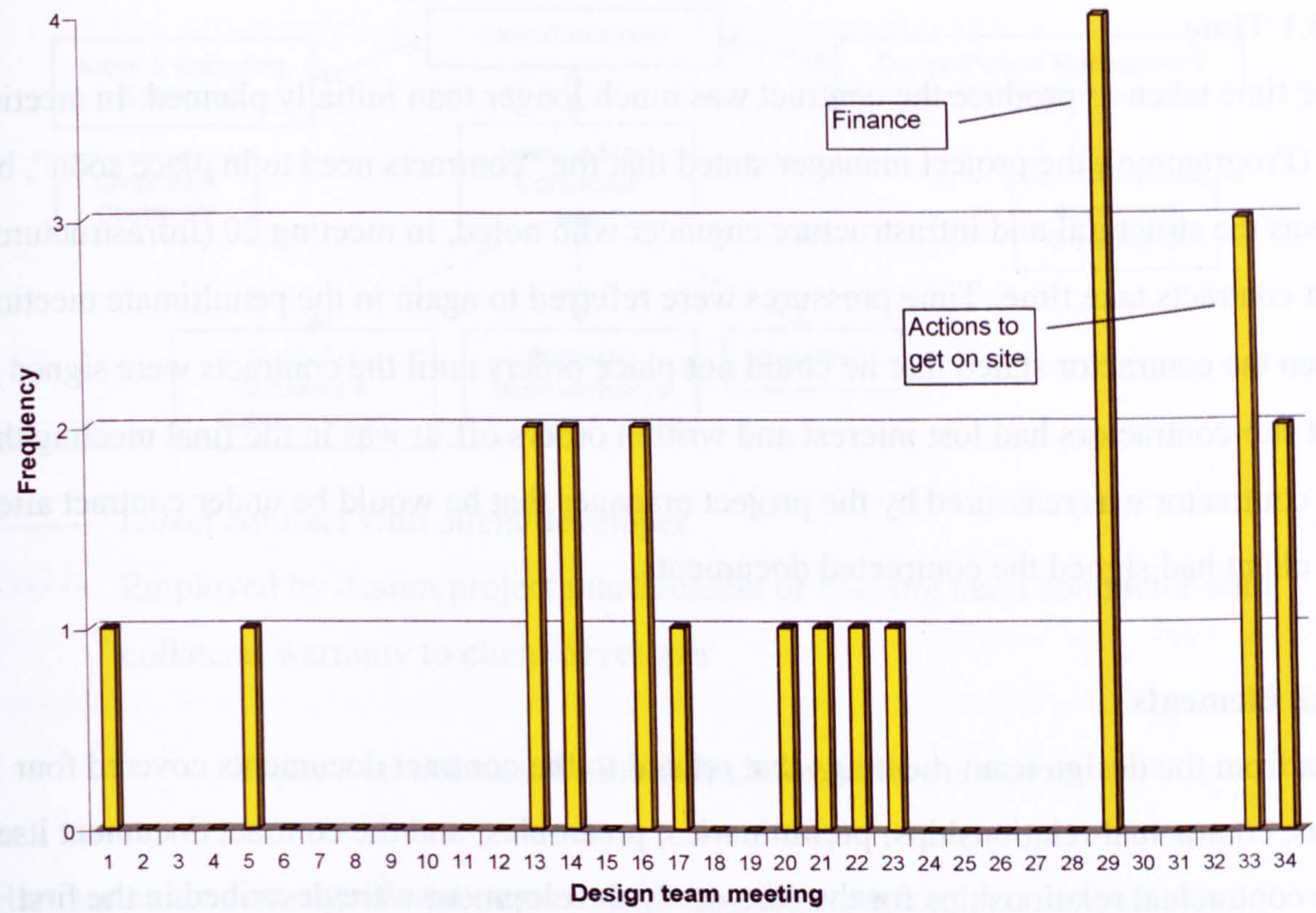


Figure 5.9: Frequency with which the contract was referred to in the design team meetings

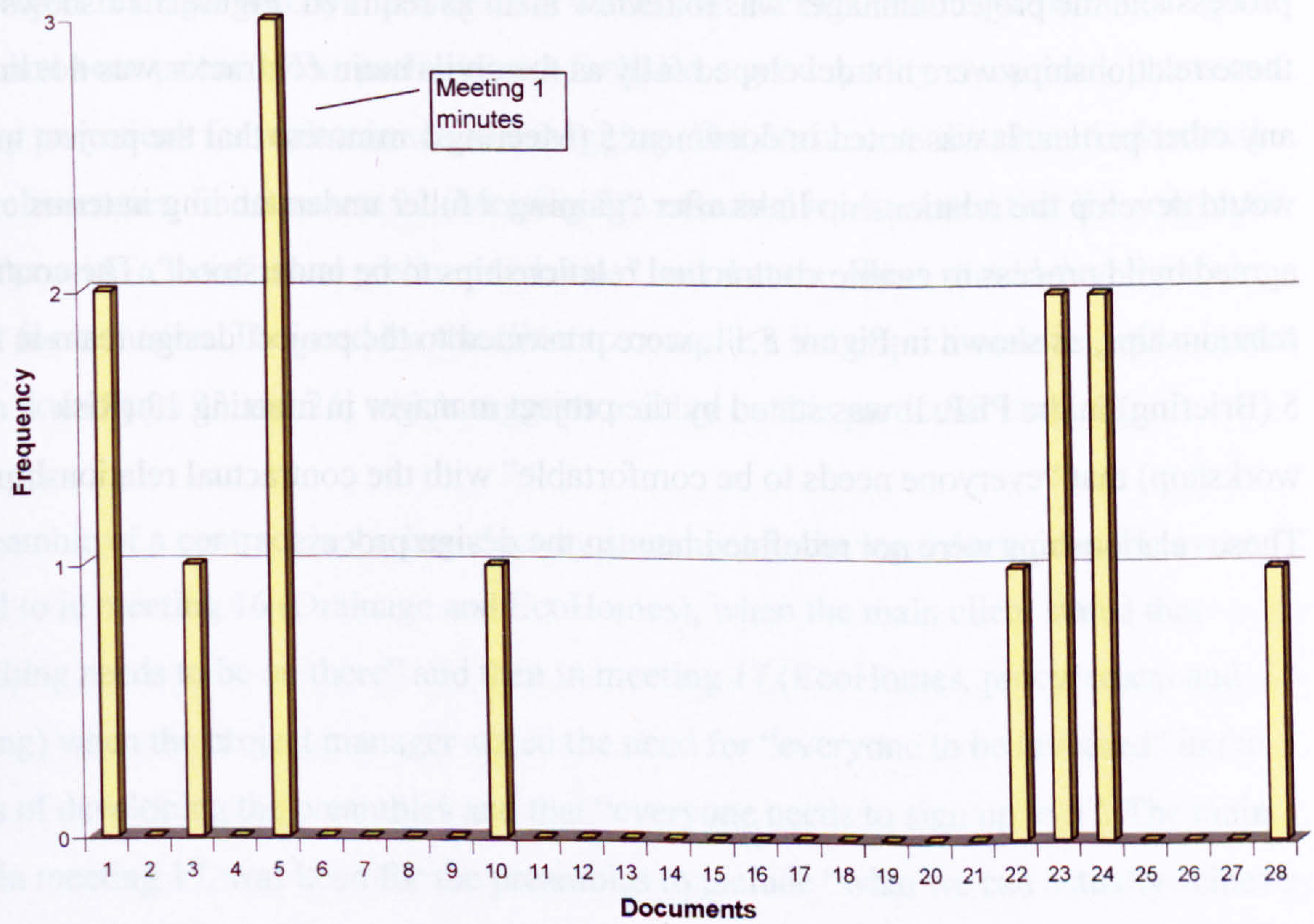


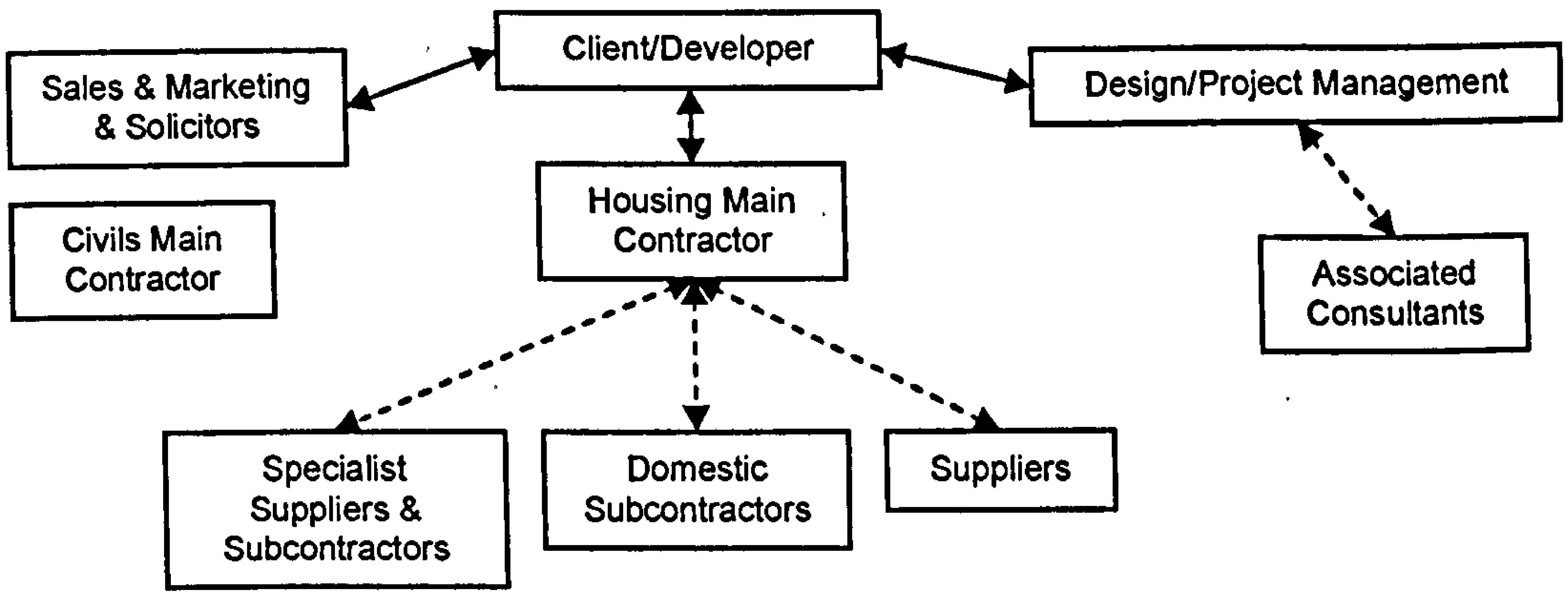
Figure 5.10: Frequency with which the contract was referred to in the documents distributed

5.6.1 Time

The time taken to produce the contract was much longer than initially planned. In meeting 14 (Programme), the project manager stated that the "contracts need to in place soon", but it was the structural and infrastructure engineer who noted, in meeting 20 (Infrastructure), that contracts take time. Time pressures were referred to again in the penultimate meeting, when the contractor stated that he could not place orders until the contracts were signed and that sub-contractors had lost interest and written orders off. It was in the final meeting that the contractor was reassured by the project manager that he would be under contract after the client had signed the completed documents.

5.6.2 Elements

Data from the design team meetings that related to the contract documents covered four areas: contractual relationships; preliminaries; preambles; and the contract document itself. The contractual relationships for the case-study development were described in the first design team meeting. These relationships were said to be flexible at the beginning of the process and the project manager was to review them as required. Figure 5.11 shows that these relationships were not developed fully as the civils main contractor was not linked to any other parties. It was noted in document 5 (Meeting 1 minutes) that the project manager would develop the relationship links after "gaining a fuller understanding in terms of an agreed build process to enable contractual relationships to be understood". The contractual relationships, as shown in Figure 5.11, were presented to the project design team in meeting 5 (Briefing) in the PEP. It was stated by the project manager in meeting 13 (Risk workshop) that "everyone needs to be comfortable" with the contractual relationships. These relationships were not redefined later in the design process.



——— Direct contract with client/developer

------ Employed by design/project management or housing main contractor with collateral warranty to client/developer

Figure 5.11: Contractual relationships, as represented in the PEP

Preliminaries are cost-significant items required by the contractor to carry out the construction work. These were first mentioned in meeting 21 (Achieving cost certainty 1) by the project manager and by meeting 29 (Finance) he declared that these had been "gone through and been priced". The preliminaries included a good quality compound, plants and monetary provisions for maintenance and snagging. The documents distributed addressed these preliminaries. In document 22 (Meeting 21a minutes) it was stated that the contractor should "provide a list of usual prelim provisions" and that the client should develop their own list for inclusion. The need for the client to compile a list of preliminaries was minuted again in documents 23 and 24, which suggests a delay on this particular issue.

The preamble of a contract is the introductory statement to the legal document. This was referred to in meeting 16 (Drainage and EcoHomes), when the main client stated that "everything needs to be on there" and then in meeting 17 (EcoHomes, procurement and tendering) when the project manager stated the need for "everyone to be involved" in the process of developing the preambles and that "everyone needs to sign up to it". The main client, in meeting 17, was keen for the preambles to include "what we can actually achieve and not just a list of expectations". He then suggested that whatever was in the preambles would need to be policed by the site foreman to ensure that they were realised in construction. The contractor suggested that the site foreman should therefore contribute to the preambles. This is an issue of particular importance to the delivery of low-energy housing as it is in the construction stage that the principles behind the scheme are delivered. The type of contract to be used was outlined in meeting 17 by the project manager as an "industry standard contract with a few ad hoc clauses". In meeting 22 (Achieving cost certainty 2) and documents 23 and 24 this was specified as being the industry's standard JCT (Joint Contracts Tribunal) contract.

5.6.3 Content

The content of the contract was first mentioned in meeting 16, but specific elements were not referred to. Instead the project manager stated a need to "identify items that will be enforced and do matter", so that "sub-contractors will be able to deliver". It was only in the penultimate meeting, 33 (Actions to get on site), that the detailed content of contract was discussed. The main client stated that the contract needed to "include waste management, lean construction and the incentives that we have discussed". These incentives refer to the contractor getting a percentage of the profit in return for delivering items below the costs set. It was stated by the contractor, however, that he had "not saved much, but we have worked hard". It was only in the very last meeting of the design process that the project manager reassured the parties present that "all EcoHomes specifications are in the contract document".

5.6.4 External actors

External actors with an interest in the contracts were noted by the project manager in meeting 13, where he stated that "the bank need to be satisfied as do EMDA". To achieve this, the need to work openly and as a team was stressed. The bank was referred to again in the penultimate meeting, where the main client said that it would need a copy of the contract and the warranties. In the final meeting the project manager told the members present that the bank had seen and agreed the contracts. EMDA was, however, not mentioned again as they had presumably been satisfied.

5.6.5 Conclusion

Comparing this process of developing contract documents to the RIBA *Plan of Work*, it is evident that contracts were only mentioned in stage J (Mobilisation). In this stage production information is issued to the contractor, which refers to stage F (Production information) and includes schedules of rates, quantities, schedules of work and revised costs. There is no indication that the contract relationships, preliminaries or preambles should be discussed prior to this stage or even that they should be discussed at all. The contract was important at the case-study development to ensure that the environmental standards were realised in the construction of the houses. In Morel et al. (2001) the "contractual agreement for the work complied with normal practice for such projects, although additional requirements were included to ensure that best environmental practices were followed" (p.1125). Action Energy (2004b) stated that "contractors tend to pay less attention to energy efficiency when cost issues arise" (p.16). To prevent this situation, it recommends that projects "prepare clear and detailed contracts with descriptions of work, budget and declaration of capacity" (Ibid, p.16). These recommendations were followed at the case-study development.

5.7 Costs

The cost of a building project is usually the main driver, as there is often limited funding available, especially when the development is being built to give a return to investors. At the case-study development, cost was just one of three drivers that related to the definition of sustainable development, the others being environmental and social considerations. Four elements that influenced the cost of the development are discussed in this section: the contractor, the EcoHomes standard, value engineering, and optional extras.

Financial issues were discussed in the case-study design process from meetings 8 (Phase 1 master plan) to 33 (Actions to get on site), as shown in Figure 5.12. This shows that cost was a topic which was revisited in most design team meetings up until meeting 29 (Finance) and that it was particularly prominent in three of the design team meetings: 11 (EcoHomes excellent); 24 (Detailed specification); and 28 (Decision making to get to cost certainty). It also shows that there were two distinct periods when costs were focused on: meetings 10 (Standards and costs) to 13 (Risk workshop); and meetings 23 (Achieving cost certainty 3) to 28.

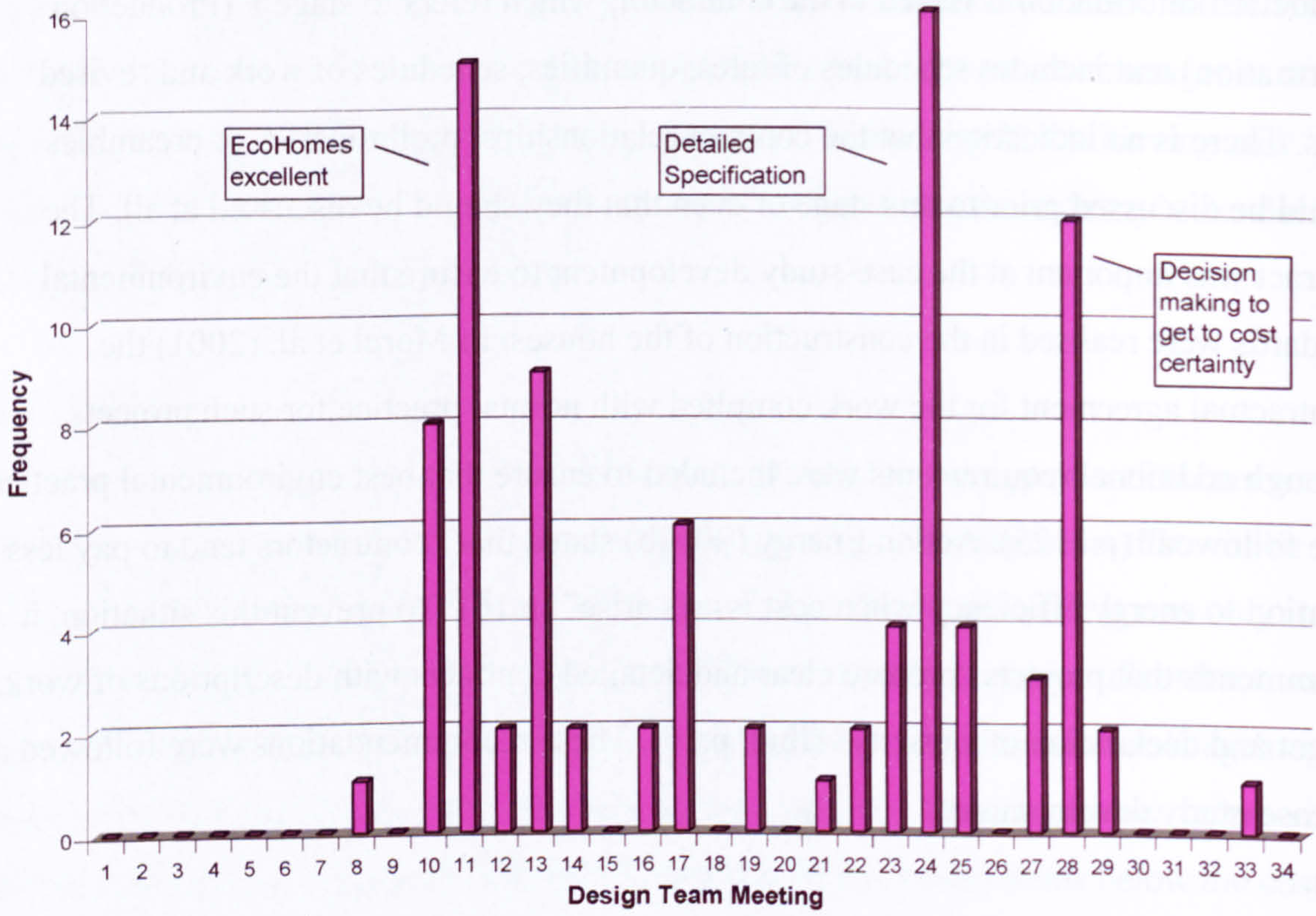


Figure 5.12: Frequency with which costs were referred to at the design team meetings

The documents distributed at design team meetings referred to cost much less frequently. This is shown in Figure 5.13, where documents that refer to costs appear towards the end of the design process, with a large spike representing document 25 (Minutes from meeting 24).

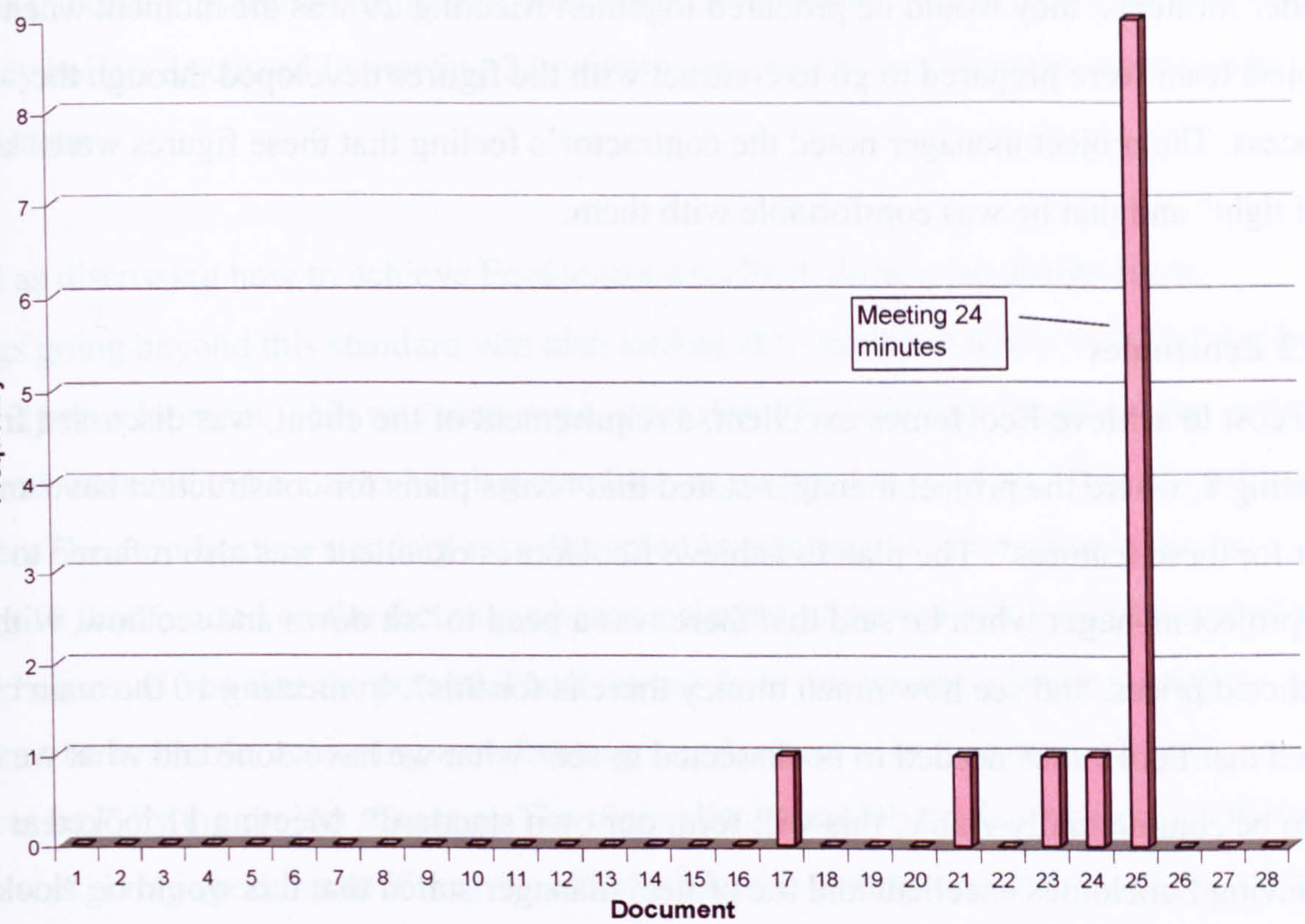


Figure 5.13: Frequency with which costs were referred to in documents

5.7.1 Contractor

The contractor is the party responsible for obtaining construction costs. These were first discussed in meeting 11 when the project manager stated that the "figures returned from the contractor were unacceptable". It was thought that this was due to a risk premium being added by the contractor due to a lack of understanding about the actual cost of more environmentally sound materials and products, with which he was unfamiliar. To rectify this, it was stated by the project manager that the contractor needed to come back with more specific prices for construction elements. The terms of the contractor's financial involvement in the project were outlined in meeting 13 when the incentives set meant that the contractor would receive £0.25 from every £1 under the cost target. The profit for the contractor was set at nine percent, which was stated as being one percent under the industry norm and three percent below what was initially sought by the contractor. These elements were discussed with the contractor and agreed. It was observed in meeting 17 (EcoHomes, procurement and tendering), by the project manager, that although the contractor could tender for items, they would be procured together. Meeting 29 was the moment when the project team were prepared to go to contract with the figures developed through the process. The project manager noted the contractor's feeling that these figures were "keen and tight" and that he was comfortable with them.

5.7.2 EcoHomes

The cost to achieve EcoHomes excellent, a requirement of the client, was discussed from meeting 8, where the project manager stated that "costs plans for construction have an extra cost for these features". The plan to achieve EcoHomes excellent was also referred to by the project manager when he said that there was a need to "sit down and see how, with predicted prices, and see how much money there is for this". In meeting 10 the main client stated that EcoHomes needed to be dissected to see "what we have done and what we can do to be commercially viable, this will form our own standard". Meeting 11 looked at achieving EcoHomes excellent and the project manager stated that this would be "looked at and all points of cost cut out in one step to stop revisiting". He continued by saying that "the most effective way of getting to EcoHomes excellent as a minimum will be discovered". This apparently contradicted what the main client had said about going beyond EcoHomes excellent to get "our own standard". The cost to achieve EcoHomes excellent was discussed in meeting 11, when the main client quoted BRE (Building Research Establishment) as saying that it would cost ten percent more than conventional housing to achieve EcoHomes excellent, while the project manager had heard five to ten percent. Ten percent was seen by the project manager as economically viable. In meeting 11, all EcoHomes points that related to EcoHomes excellent were discussed, with some cost implications raised. In meeting 13 it was stated that an extra 7.5% had been added to achieve EcoHomes excellent, which was taken as the average of the figures mentioned in meeting 11. This figure was decided on even though no evidence or details about these figures had been provided. In meetings 16 (Drainage and EcoHomes) and 17 some specific EcoHomes points (insulation, water run-off and ecological assessment) were listed by the client as being cost-effective points that needed to be scored. The cost implications of some additional elements were seen as worthwhile in relation to their additional performance.

This was the case for thermal insulation, mentioned in meeting 16, and also the high-efficiency boilers discussed in meeting 23, which were said to be £73 more expensive by the contractor.

As well as discussing how to achieve EcoHomes excellent, during the design team meetings going beyond this standard was also looked at to establish a new standard for the case-study development. This was seen as an extension of EcoHomes excellent, but at the outset was intended to be a zero-heating standard, as outlined in meeting 10 by the project manager. The zero-heating standard was discarded in meeting 11, after discussions in meeting 10 that focused on the fact that a heating system of some kind would be needed to sell the houses. Given that the potential cost saving from not having a heating-system would not be available, achieving zero-heating was deemed to be "expensive" and "unnecessary" by the project manager. The main client stated that when he asked audiences that he was giving speeches to if they would buy a house without a heating system, only a very few said that they would. This was agreed by all parties involved, with the second client stating that this was fine as "EcoHomes excellent +" was to be delivered. The project manager, in meeting 11, said that "it will be a case of seeing what money is left to be spent on EcoHomes excellent +". This was reinforced in meeting 19 (M&E drawings 2), when he stated that "options are still available if money is".

5.7.3 Value engineering

Value engineering is the process of identifying alternative materials, products or services capable of performing the same function whilst providing added benefits, such as a reduction in cost (Thomson and Austin, 2001). A need for value engineering was first mentioned by the contractor in meeting 21 (Achieving cost certainty 1), towards the end of the design process, and the discussions surrounding it continued until meeting 29. Value engineering made up most of the references to cost throughout this period. The two meetings, 24 (Detailed specification) and 28 (Decision making to get to cost certainty), that focused most on value engineering are highlighted with spikes in Figure 5.12. In meeting 22 (Achieving cost certainty 2) the project manager reiterated the need for value engineering as the price per square metre was higher than desired, but he was confident that "we can get the figure we want; there is potential for tightening". In meeting 24 every aspect of the specification of one of the house types was examined by the design team to see if there was any scope for cost reduction.

The cost reductions identified in meeting 24 could be categorised into three groups: removal, substitution, and simplification of architectural detail. Elements that were removed included: the need for ceilings to support hoists; the use of non-PVC (plasticised polyvinyl chloride) wiring; the provision of floor covering in the bathroom and hall; curtain tracks; shelves in the under-stairs cupboard; and coat hooks. Many of these items became optional extras for buyers to specify at an extra cost when purchasing the houses. Elements that were considered for substitution included: thermal insulation, cavity closers, internal doors, chimney pots and the stair construction. Elements that were to be redesigned included the eaves details, window sills and window enclosures. These cost reductions were mainly driven by the contractor to reduce the construction cost for the project and get to a final price. During this process the architect tried to justify why some of these elements had been included, such as the enclosure for the window which was set back to protect the timber window frames from the weather. All of these elements were discussed again with the main client in meeting 28, with the final decisions left to him, as instructed by the project manager in meeting 27 (Review of last 3 meetings). Meeting 29 saw value engineering come to a close with the project manager stating that many items had been "re-priced by going through every point and coming up with realistic prices, which there is no reason why the contractor can't build for". This reduced the costs of many items significantly. Value engineering was also referred to in many of the documents distributed at the design team meetings, the main one of these being document 25, which was the minutes for meeting 24 which listed all the value engineered items. The process of value engineering at the case-study development seemed to rely mainly on the removal of items, rather than the reengineering of them.

5.7.4 Optional extras

Costs were discussed in relation to optional extras that would be available to buyers. These ranged from television connections in every room, as mentioned by the project manager in meeting 13, to people choosing to install renewable energy technologies, such as solar thermal, which was raised by the client in meeting 28. Although the houses were designed to be 'sustainable' it was felt that this should not come at a cost premium to buyers, this was outlined by the project manager in meeting 11, when he stated that "we need to build safe and not rely on premiums being paid". Throughout the design process there were comparisons to conventional housing developers in terms of meeting similar build costs. These all came from the project manager and referred to three issues. The first, in meeting 11, was that if white goods were provided then the competitors could sell their properties for £2000 less. The second, also in meeting 11, was that conventional housing developers "want to achieve the bottom line to meet building regulations at the cheapest costs possible". Thirdly, in meeting 27 (Review of last 3 meetings), he said that what conventional developers provide as standard needs to be considered, as it was seen as pointless paying more to provide items that others would not include. The difference between these conventional developers and the case study was, however, seen as a huge advantage by many members of the project team.

5.7.5 Conclusion

Comparing how costs were dealt with through this project with the RIBA *Plan of Work,* it is apparent that both processes consider cost throughout. Cost is mentioned in stages A (Appraisal), C (Outline proposals), D (Detailed proposals) and E (Final proposals) as well as F (Production information) and G (Tender documents) as part of the tendering process in the *Plan of work*. In each of these stages cost is referred to in a fairly simplistic manner, with no consideration given to the fact that costs may not be within the expected targets. The use of value engineering is not mentioned, which may be due to the fact that, as seen at the case-study development, it can be detrimental to the principles of the project, especially when substitutions are made for inferior products or materials. In Bogenstätter (2000) it was explained that "calculating construction and operation costs early in the design process is no easy matter" (p.378) as data are "rare and often insufficiently defined" (p.378) and "often considered as commercially confidential" (p.378). Weingardt (1996) suggested that for value engineering to be successful, "consulting engineers should be the prime designers, or at least play a more prominent role on the architect's team" (Ibid, p.50). At the case-study development, however, value engineering was stated as being undertaken by the contractor, with both the M&E consultants and the structural and infrastructure engineers not consulted on design and specification changes. This process of value engineering was, however, more about removal of items than providing engineering solutions. This process almost certainly proved detrimental to the environmental impact of the houses.

5.8 Chapter conclusions

The combined frequency with which the six aspects of the design process were discussed or documented is illustrated in Figures 5.14 and 5.15. Figure 5.14 summarises the design team meetings and shows that several aspects were present throughout the entire process, such as procurement, contracts and the project team, whereas others were more concentrated in one period. Costs and tendering were more concentrated towards the middle and end of the design process, with principles concentrated at the beginning. Figure 5.14 shows two design team meetings where none of the aspects were referred to. This is because these meetings dealt with superficial changes to the house designs and going through M&E drawings. Figure 5.15 shows a slightly different picture, with tendering not being mentioned at all and costs mentioned only towards the end of the process. The documents do not give as accurate an account of the design process as the design team meetings because they were mostly produced by the architects' practice and were often architectural drawings that related to specific aspects of the design, rather than to the design process in a more holistic sense.

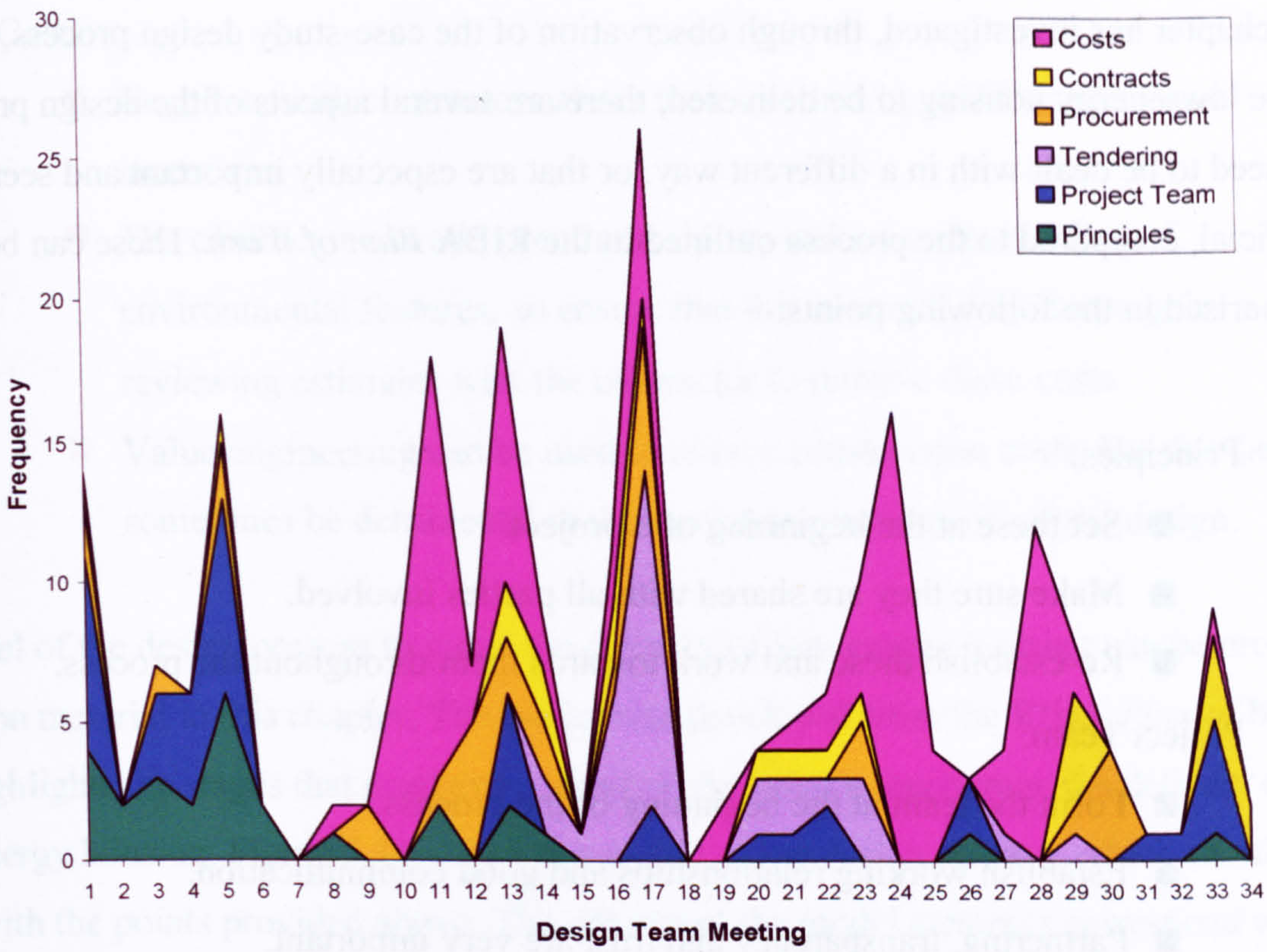


Figure 5.14: Frequency with which aspects of the design process were referred to during design team meetings

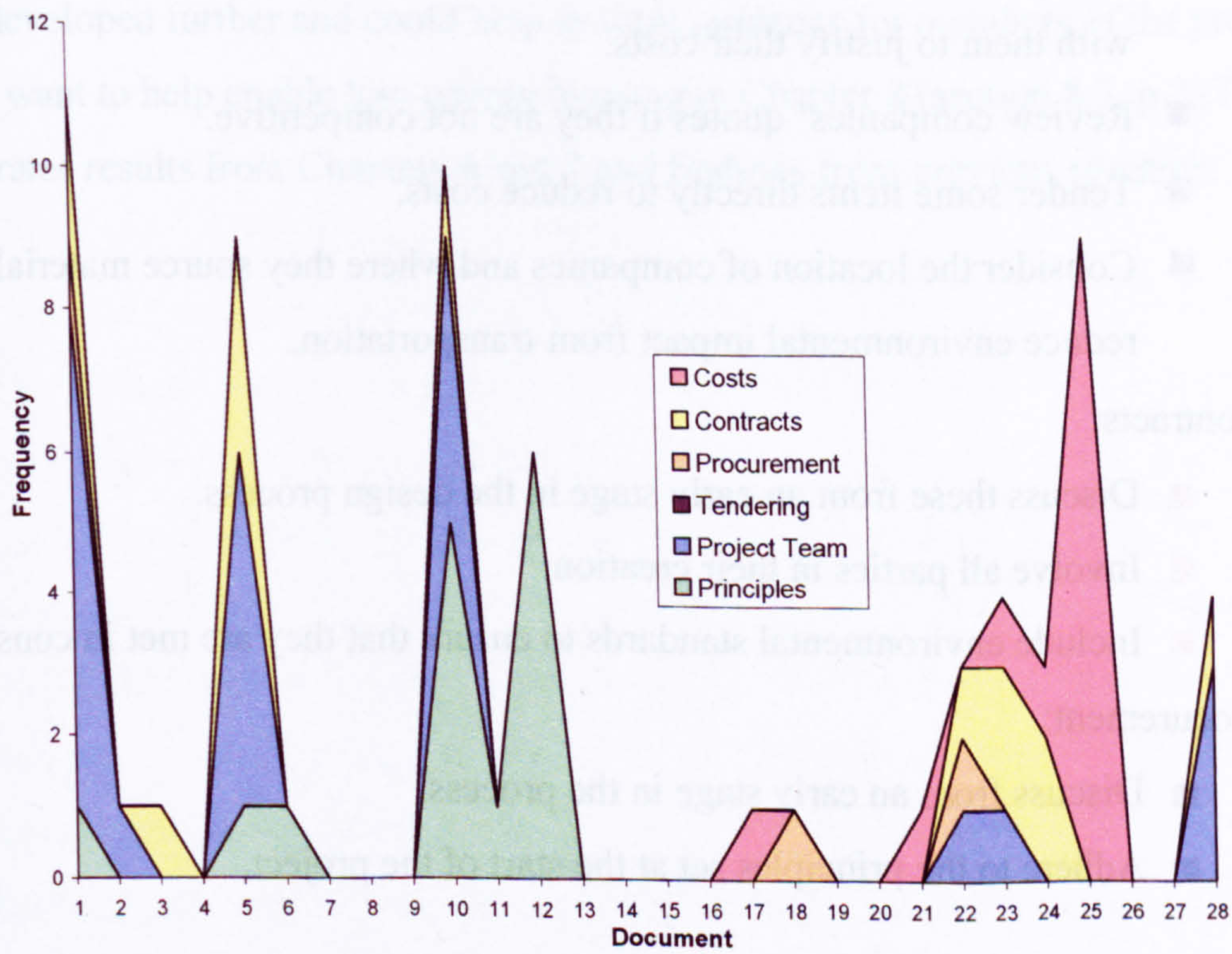


Figure 5.15: Frequency with which aspects of the design process were referred within the documents

This chapter has investigated, through observation of the case-study design process, that to enable low-energy housing to be delivered, there are several aspects of the design process that need to be dealt with in a different way, or that are especially important and seem to be beneficial, compared to the process outlined in the RIBA *Plan of Work.* These can be summarised in the following points:

- Principles:
    - Set these at the beginning of a project.
    - Make sure they are shared with all parties involved.
    - Re-establish these and work towards them throughout the process.
- Project Team:
    - Form the team at the beginning of the process.
    - Establish working relationships and good communication.
    - Partnering, transparency and trust are very important.
- Tendering:
    - Figures should be renegotiated with sub-contractors by arranging meetings with them to justify their costs.
    - Review companies' quotes if they are not competitive.
    - Tender some items directly to reduce costs.
    - Consider the location of companies and where they source materials to reduce environmental impact from transportation.
- Contracts:
    - Discuss these from an early stage in the design process.
    - Involve all parties in their creation.
    - Include environmental standards to ensure that they are met in construction.
- Procurement:
    - Discuss from an early stage in the process.
    - Adhere to the principles set at the start of the project.

- Costs:
  - Negotiate with contractors about their overheads, profit margins and incentives.
  - The contractor can add premiums due to lack of understanding of environmental features, so ensure that this is avoided by thoroughly reviewing estimates with the contractor to remove these costs.
  - Value engineering can be used to reduce construction costs, but this can sometimes be detrimental to the environmental aspects of the design.

A model of the design process to guide the delivery of low-energy housing can be proposed based on material in this chapter. The model was developed from the RIBA *Plan of Work* and highlights the stages that need extra attention (in bold) to encourage the delivery of low-energy housing. Figure 5.16 shows this model of the design process, which should be used with the points provided above. The colours of the model elements correspond with those of the different sections in this chapter. The model has five new stages: formation of the project team; set and agree principles; design brief; contracts; and procurement. This model is developed further and could help to form guidance for members of the project team who want to help enable low-energy housing in Chapter 8 (section 8.5, p.227), where it incorporates results from Chapters 6 and 7 and findings from previous research.

A. Appraisal

B. Client brief

C. Formation of project team

D. Set and agree principles

E. Design brief

F. Outline design

G. Detailed design

H. Final design

I. Tendering information

J. Tender packages

K. Tender actions

L. Contracts

M. Procurement

N. Construction to completion

O. Handover

Figure 5.16: Model of the design process to encourage the delivery of low-energy housing

6. Design Decisions: exploring decisions that affect the environmental impact of houses

The design process comprises a series of decisions that are made by the project team. Every aspect of a building is determined by these decisions, as they specify each detail of the building fabric, services and construction techniques and therefore dictate overall building performance. Numerous factors influence decision making in the design process, but can be categorised into three main areas that relate to sustainable development: economic, social and environmental. In conventional building projects the focus is often economic, as business is usually dictated by financial gain. Public buildings, by contrast, may look at financial and social aspects. This chapter examines the decisions made within the design process that affected the environmental impact of the houses at the case-study development. The aim is to demonstrate how these decisions were made within the design process and to identify lessons for future housing developments. Decision making in the design process has received little attention in academic or non-academic publications, as described in Chapter 2 (section 2.4, p.38).

Eight decisions were identified that affected the environmental impact of the houses on the case-study development. These were identified from template analysis undertaken on design team meeting data, documents distributed at these meetings and construction meetings. The methods used to analyse these data were described in Chapter 4 (section 4.2, p.60) and the methodology used to combine these methods was described in section 4.3.2 (p.74). The predefined terms used to initiate the template analysis and produce the analysis of the eight decisions for discussion were developed from previous literature. These were grouped into broader themes for initial analysis and included: heating, insulation, materials, timber, water, ventilation, lighting and other. The template was developed and analysis of the data was undertaken over several iterations, as described in Chapter 4 (section 4.2.3, p. 67). The final template used to code the data is presented in Appendix E, p.273. This process identified the eight decisions that affected the environmental impact of the case-study houses. These were:

- Heating/Hot water
- Insulation
- Materials
- Building elements
- Water
- Ventilation
- Lighting
- Standards
- Renewable energy

The decisions were analysed using two types of decision analysis to investigate the structure of the decision and then to evaluate it. These were detailed in Chapter 4 (section 4.2.6, p.71).

The decisions are discussed according to their significance in terms of the EcoHomes credits, as this was the standard that the case-study houses were being developed in accordance with. EcoHomes was introduced in Chapter 1 (section 1.2, p.11) and was the environmental standard used by the case-study development. Table 6.1 presents all the EcoHomes credits, along with their overarching topics, credits available and the percentage of total credits available assigned to each topic and sub-topic.

Topic	Credit	Sub-topic	Credits available	% of credits
Energy	Ene 1	CO_2 emissions	10	11.24
	Ene 2	Building envelope performance	5	5.62
	Ene 3	Drying space	1	1.12
	Ene 4	Eco labelled white goods	2	2.25
	Ene 5	External lighting	2	2.25
			Total	22.48
Transport	Tra 1	Public transport	2	2.25
	Tra 2	Cycle storage	2	2.25
	Tra 3	Local amenities	3	3.37
	Tra 4	Home office	1	1.12
			Total	8.99
Pollution	Pol 1	Insulation ODP (ozone depletion potential) and GWP (global warming potential)	1	1.12
	Pol 2	NOx emissions	3	3.37
	Pol 3	Reduction of surface runoff	2	2.25
	Pol 4	Zero emission energy source	1	1.12
			Total	7.86
Materials	Mat 1	Timber: Basic building elements	6	6.74
	Mat 2	Timber: Finishing elements	3	3.37
	Mat 3	Recycled materials	6	6.74
	Mat 4	Environmental impact of materials	16	17.98
			Total	34.83
Water	Wat 1	Internal water use	5	5.62
	Wat 2	External water use	1	1.12
			Total	6.74
Land use and ecology	Eco 1	Ecological value of site	1	1.12
	Eco 2	Ecological enhancement	1	1.12
	Eco 3	Protection of ecological features	1	1.12
	Eco 4	Change of ecological value of site	4	4.49
	Eco 5	Building footprint	2	2.25
			Total	10.10
Health and well being	Hea 1	Daylighting	3	3.37
	Hea 2	Sound insulation	4	4.49
	Hea 3	Private space	1	1.12
			Total	8.98

Table 6.1: EcoHomes credits

The decisions are discussed in descending order of their contribution to the overall score for the EcoHomes standard. The decisions percentage scores according to EcoHomes are as follows:

1. Standards – 100% (encompassing all the topics and sub-topics)
2. Materials – 34.83%
3. Water – 7.87%
4. Building elements – 5.62%
5. Insulation – 5.62%
6. Lighting – 5.62%
7. Heating and hot water – 3.37%
8. Renewable energy – 1.12%
9. Ventilation – 0%

The rest of the EcoHomes credits relate to aspects that were beyond the control of the case-study development, or they do not relate to the houses examined in this study.

Each of the proceeding sections follows the same structure, starting with a short introduction followed by an illustration of the time period in which decisions were made and the structure of the decision-making process. The figures in this chapter do not represent the time period over which decisions were made. They do, however, show at which design team meetings (represented by a 'D') and construction meetings (represented by a 'C') each decision was discussed. A discussion of the key themes for each decision is then presented and the decision-making structure is discussed. This is followed by a short conclusion.

The design team meetings referred to in this chapter were presented in Table 3.1 (Chapter 3, section 3.2.1, p.51) which shows when these meetings occurred and how far apart they were. The construction meetings attended were outlined in Table 3.4 (Chapter 3, section 3.2.4, p.56).

All quotes presented, unless otherwise stated, are taken from field notes made from these data sources. Some of the decisions made for elements identified were made outside the design team meetings, but most of these were recapped in subsequent meetings.

6.1 Environmental standard

The environmental standards set and adhered to for a project can significantly change the environmental impact of a building. In the case-study development, EcoHomes excellent, described in Chapter 1 (section 1.2, p.11) was used as a minimum starting point for the houses. To achieve an EcoHomes excellent standard, 70% of credits listed in Table 6.1 would be necessary. An energy standard of zero-heating was originally set in the planning conditions described on p.91. This would have meant that the houses would have been designed so that no active heat sources were required for space heating. This section explores how the environmental standard evolved from zero-heating to EcoHomes excellent and what implications that had for the houses.

The environmental standard was discussed from design team meeting 1 (Introduction to process) to construction meeting 9 (Decision meeting 3). This represented the entire design process, which spanned a period of 23 months. Figure 6.1 shows the meetings in which the environmental standard was discussed for the four elements that informed this decision: zero-heating, covenants, EcoHomes and beyond EcoHomes. There was a concentration of discussions about these elements between design team meetings 10 (Standards and codes) and 16 (Drainage and EcoHomes). Figure 6.1 also shows the phases of the decision-making process. Identification took place between design team meeting 1 and 14 (Programme), development of solutions from design team meeting 8 (Phase 1 master plan) to construction meeting 8 (Decision meeting 2), and the selection of solutions from design team meeting 14 to construction meeting 9. These phases are discussed in more detail for each of the elements in the following paragraphs.

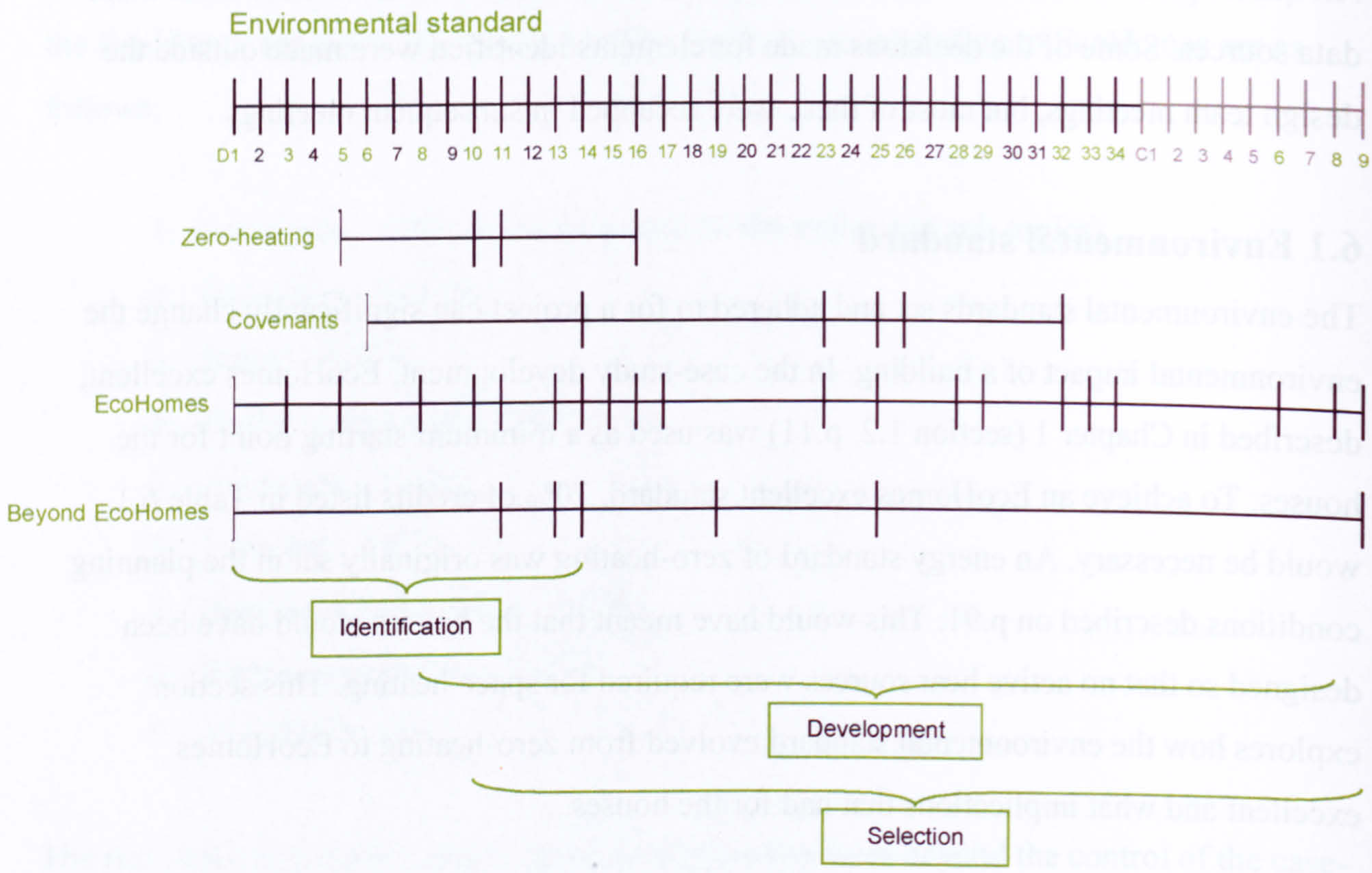


Figure 6.1: Time-line and phases of the decision-making process for the environmental standard

6.1.1 Zero-heating

The zero-heating standard for the case-study houses was discussed from design team meeting 5 to 16, shown in Figure 6.1. The zero-heating standard was identified in meeting 5 (Briefing), when the planning conditions for the houses were presented. These also included a list of U-values to be met in relation to this standard. The provision of solar hot water on all south facing roofs, rainwater harvesting systems and ground source heat pumps were also specified. These were planning conditions that enabled the case-study development to avoid having to provide any affordable housing because "all houses will be affordable as they will have reduced running costs", as stated in the design brief distributed in meeting 5. In design team meeting 10 it was already apparent that the majority of the project team thought that the standard set in the planning conditions was too ambitious, with the project manager saying that they "need to talk to the planners to change the requirement on the development from zero-heating to achieving EcoHomes excellent". This idea was developed through meeting 10, with discussions based around the idea that "zero-heating would be fine if money was spent on construction rather then heating, but the houses will not be sellable without heating" which was explained by the project manager and agreed by the clients. The main client stated that he had asked at several events that he had spoken at around the UK if people would be willing to buy a house without a heating system, with very few positive responses. By the end of meeting 10 the EcoHomes standard was the focus of the debate surrounding the environmental standard for the houses. In meeting 16, the project manager stated that the principal architect had been in negotiations with the planners and that EcoHomes excellent was now expected.

6.1.2 Covenants

Covenants on housing developments can be used to restrict the activities of residents once they have moved in. In the case-study development, these were discussed from design team meeting 6 (Changes to designs) to 32 (Progress update and revise site plan) and covered areas in which covenants could be used to make sure that residents did not adversely affect the environmental performance of the houses. The issue was identified in meeting 14, when the project manager stated that a covenant would be difficult to enforce without a management committee, which could mean an annual cost to householders. The main client was keen to ensure that any covenant precluded uPVC conservatories. This was mentioned again in meeting 23 (Achieving cost certainty 3), when the main client stated "I don't want to spend lots of time designing these houses for someone to whack on a huge uPVC conservatory". In meeting 25 (Meeting with sub-contractors), it was noted by the main client that solar thermal systems, even though they may not need planning permission in the future, would need permission from the developer. The project manager stated that "it is felt that the prettiest system would be wanted, which could involve solar thermal collectors being integrated within the roof tiles". In meeting 32 the covenants were said to be finalised by the project manager, containing some elements that related to the environmental standard and some that did not. The covenant included conditions that related to: drainage; restrictions on greenhouse and shed sizes; no parking of caravans; and no uPVC conservatories.

6.1.3 EcoHomes

The EcoHomes standard was discussed from design team meeting 1 to construction meeting 9, as shown in Figure 6.1. The discussion surrounding EcoHomes was made up of many aspects, which can be divided into three groups: the overarching standard; the credits involved in achieving the standard; and costs. The overarching standard will be discussed in this paragraph and the costs and credits discussed in the following two paragraphs. The overarching EcoHomes excellent standard was discussed from design team meeting 1, when the client stated that a starting point was needed and that EcoHomes excellent would be the minimum standard to be achieved. In design team meeting 10 the project manager admitted that he had little understanding of the standard, but was ready to learn as much as he could. There was some confusion over the standard to be achieved in this meeting, when the second client stated that the "starting point was Building Regulations", but this was soon corrected by the main client, who stated again that the starting point was EcoHomes excellent. In meeting 14 the project manager stated that the "process has been based around the principles, we've not even looked at EcoHomes until now". He then went on to say, in meeting 25, that trade offs would need to be made between sustainability and cost. In meeting 34 (Pre-start meeting) it was confirmed that the EcoHomes requirements had been incorporated into the contract documents.

The extra cost for the EcoHomes standard was identified in meeting 8 (Phase 1 master plan), but the project manager was keen not to let the M&E consultants "loose with the figures" as he was worried that they might add too many technical features. In meeting 10, the cost was referred to by the main client, who stated that the EcoHomes credits needed to be listed to see what had been done and what could be done that would be commercially viable. This then formed the basis of the formalised developer's standard. In meetings 10 and 11 (EcoHomes excellent) the additional costs to achieve EcoHomes excellent were discussed, with estimates of five to ten percent given. These were seen as reasonable and commercially viable by all. In meeting 13 (Risk workshop), 7.5% was allocated as the additional cost allowed to achieve EcoHomes excellent. This was decided upon as it was the average of the earlier estimates. It was drawn to the attention of the project team in meeting 10, by the author of the present thesis, that this figure could rise dramatically as contractors often quote much higher prices for environmental features due to lack of understanding. This was confirmed in meeting 11 when the project manager stated that the figures returned by the contractor were unacceptable and that they needed to go back to the house designs. He agreed that the additional cost was added to cover risk due to lack of understanding and that they "need to get more specific prices for items from the contractor".

The credits involved in achieving the standard that was discussed in the design team and construction meetings included the provision of: bike storage; drying space; private space; and white goods. Apart from the white goods they were all initially identified in meeting 11, when each credit was discussed and an initial prediction of how many points could be achieved was made. These were then developed through the design team meetings, with various selections being made and then reconsidered as the process continued. The white goods were initially discussed in design team meeting 3, when it was decided that they would not be provided. However, in construction meeting 9 it was decided that a hot and cold filled triple-A rated washing machine and dishwasher were to be provided as well as an A+ rated fridge/freezer. The hot and cold fill of the dishwasher and washing machine was seen as very important by the main client, as he wanted to take advantage of solar thermal panels if they were installed. Bike storage for the houses was to be provided in 50% of the dwellings to gain one EcoHomes credit rather than 95% for two credits, as this was seen as unnecessary. This was estimated to cost £23,000 for the entire development for one EcoHomes point, which was not seen as unreasonable by the project manager or the main client. Drying space and private space were both decided on fairly quickly, with all houses and flats being provided with a space both private to them and that they could dry washing in.

6.1.4 Beyond EcoHomes

The discussion of achieving an environmental standard beyond EcoHomes excellent took place between design team meeting 1 and construction meeting 9, as shown in Figure 6.1.

The idea to go beyond EcoHomes excellent was expressed by the main client in the first design team meeting. It was also stated by the main client in this meeting that a standard should "be decided on and stuck to". Achieving a standard beyond EcoHomes excellent was discussed and solutions developed during meeting 11. It was only in meetings 13 and 14 when it was decided that any money left after achieving EcoHomes excellent was to be spent on going beyond this standard. One aspect that would have achieved a benefit over EcoHomes excellent was remote monitoring of gas, electricity and water, with feedback provided to residents. This was discussed in meetings 19 (Surfaces and finishes) and 25, but in construction meeting 9 it was revealed that only water was to be remotely monitored on phase 1a of the development. This was due to cost, as remote monitoring does not come as a standard from the service providers and equipment would have been needed to feed back this information to the householders.

6.1.5 Conclusion

This section has looked at the decisions undertaken to develop the environmental standard for the case-study houses. The standard selected was EcoHomes excellent as a minimum. After much deliberation in relation to the zero-heating standard set out in the planning requirements, this was rejected. There was no affordable housing provision on the site because of the original planning conditions. These were renegotiated to EcoHomes excellent, but affordable housing was still not required. EcoHomes was not understood by the project manager at the beginning of the process, but because he was willing to learn it was more easily incorporated into the process. The estimated cost of achieving EcoHomes excellent was set at 7.5% above conventional housing from an estimate by the project manager. The initial cost estimate from the contractor was seen as unrealistic by the project manager as he felt that the contractor had added a cost premium for environmental features that he was unfamiliar with. The cost was renegotiated by obtaining specific costs for unfamiliar items. The project team developed a series of covenants for the houses to protect the principles behind the development.

Lessons inferred from the observation of the case-study design process for future developments in relation to environmental standards are four-fold. Firstly, an environmental standard needs to be created that is engaged with by members of the project team; incorporating the principles of the development and that can be implemented successfully within the budget available. This environmental standard then needs to be followed and communicated to all parties involved in the design process, with additional information/training provided where necessary. Secondly, specific prices should be obtained from the contractor for environmental features that could have cost premiums added to them due to lack of understanding. Thirdly, covenants to protect the principles of the development should be considered to stop residents increasing the environmental impact of the houses after construction. Finally, great consideration should be given to the provision of affordable housing as it is a vital resource. Although the case-study development made the houses 'affordable' through lower running costs, there is still a huge capital cost involved in buying any house and long-term savings may not help those on lower incomes to enter the housing market in the first place.

6.2 Materials

Materials used for constructing a house have a profound affect on its environmental impact, as their properties dictate how the building will perform. The houses at the case-study development were, from the very beginning, to be of traditional masonry construction. This was due to the fact that the clients were keen for the development to be seen as familiar to potential buyers and also so that the contractor was familiar with the construction method selected.

Materials for the houses were discussed from meeting 5 (Briefing meeting) to meeting 27 (Review of last 3 meetings), which represented 12 months of the case-study design process. Figure 6.2 shows when materials were discussed in the design process and also presents the four elements under the broad theme of materials. These four elements are: recycled materials; timber; specification of materials; and source of materials. Figure 6.2 shows the three phases of the decision-making process for the selection of materials. This shows that the problem was identified between meetings 5 and 12 (Materials to be specified), solutions were developed through meetings 12 to 24 (Detailed specification) and selection made from meetings 13 (Risk workshop) to 27. There was a concentration of discussion surrounding materials fairly early on in the design process; between meetings 11 (EcoHomes excellent) and 17 (EcoHomes, procurement and tendering). The phases of decision making and evaluation of the decision will be looked at for each of the four elements in the following paragraphs.

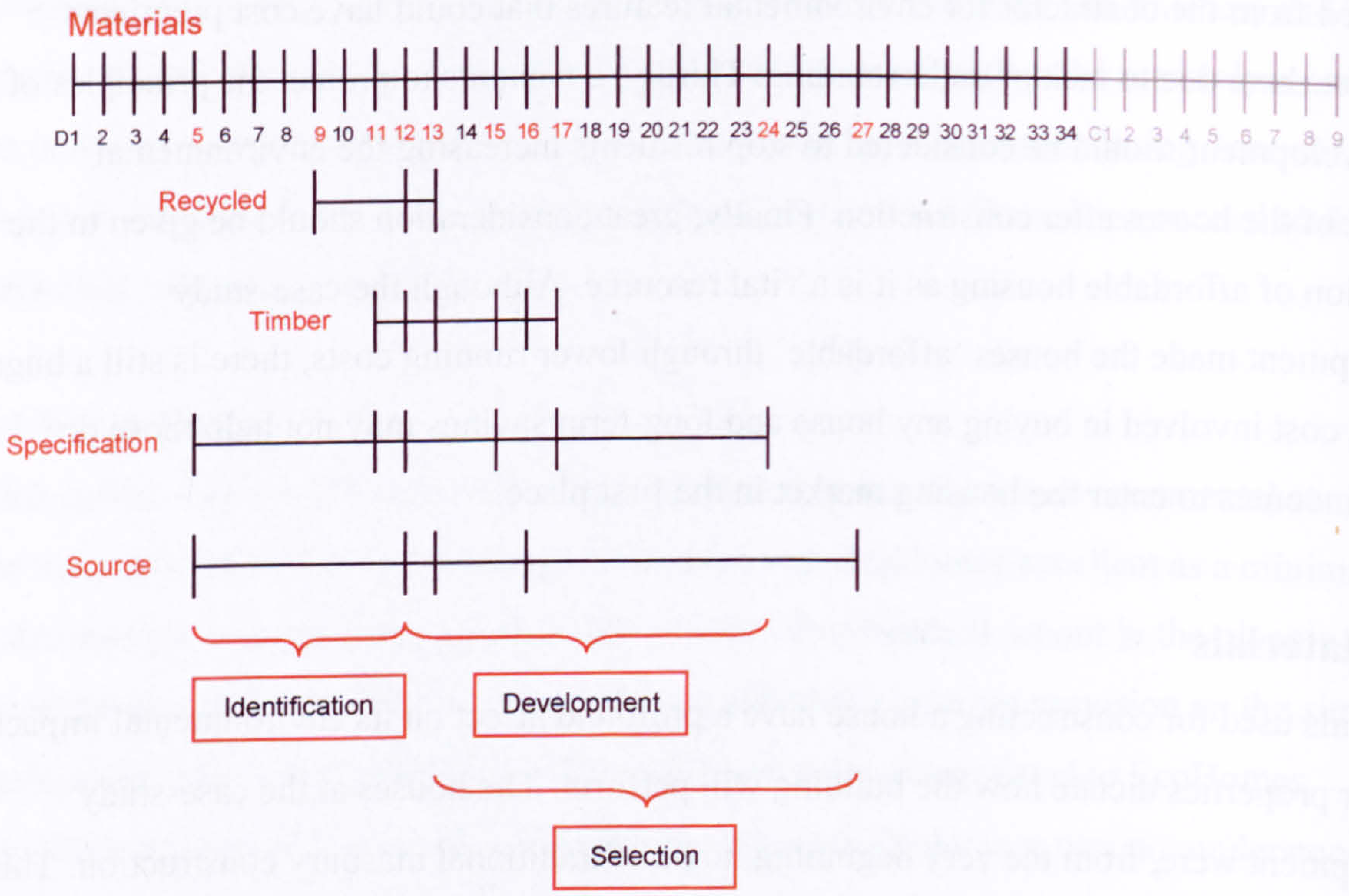


Figure 6.2: Time-line and phases of the decision-making process for the selection of materials

6.2.1 Recycled materials

Using recycled materials in the houses was something pursued by the main client. During the discussions that took place between meetings 9 (Surfaces and finishes) and 12, he gave many examples of recycled materials that could be used for particular components. In meeting 9, he suggested using recycled paving and a material made from recycled plastic bottles for the garage doors and in meeting 12 he suggested using recycled materials for the kitchen. The contractor also seemed to have an interest in using recycled materials. In meeting 12 he asked whether hardcore would be recycled on site and whether recycled tiles were being used for the roofs. None of these ideas were followed up in any depth during the design team meetings, as further information was not provided by those parties advocating them. The only element that was recycled was the hardcore, which would save the project both transportation and additional material costs.

6.2.2 Timber

Timber was to be used throughout the houses on the roof structure, first floor construction, partition walls, joinery and stairs. Timber can have a low or high environmental impact, depending on the type and source (Lazarus, 2005). Timber was discussed between meetings 11 and 17. In meeting 11 the principal architect said that he wanted 100% credits for timber in relation to the EcoHomes assessment and in meeting 12 it was decided that the author of the present thesis would develop a timber policy for all the timber used in the houses. This timber policy included: a general introduction about selection; accreditation; protection; products; related EcoHomes credits; reuse and recycling; waste issues; detailing; and a list of manufacturers and suppliers. The implementation of the timber policy was discussed in meetings 15 (Surface materials and EcoHomes) and 16 (Drainage and EcoHomes), when concern was raised about the contractor adopting the policy. This seemed to be of particular concern to the second client, who stated, in meeting 15, that it needed to be "gone through with everyone; designers, suppliers, contractor, subbies etc.", but this review was cancelled in both meetings 16 and 17. In meeting 17 the contractor explained that he was to use timber that would be FSC (Forestry Stewardship Commission) certified, which was one of the recommendations of the timber policy. The other recommendations from the timber policy were not discussed and it was unclear whether they were acted upon.

6.2.3 Specification

Specification of materials was discussed from meetings 5 to 24. In meeting 5 the external materials were specified as natural rather than manmade wherever possible. It was also stated that they would be chosen for their performance and longevity as well as their appearance. EcoHomes was a driver for some of the material selections and was referred to in meeting 11 by the project manager. In meeting 12 this consideration developed and the

Green Guide to Specification (Anderson et al., 2002) was referred to, as well as manufacturers' environmental policies, to help select materials.

6.2.4 Sourcing

Sourcing materials and labour was first discussed in meeting 5, when the main client stated the desire for these to be local. The discussion continued until meeting 27. The two main materials used for the construction of the houses, brick and block, were discussed in meeting 12, when the job architect and project manager reminded members of the project team that these needed to be locally sourced. The brick was, however, not sourced from the closest manufacturer due to colour issues identified in meeting 16.

6.2.5 Conclusion

Decisions about selection of materials for the case-study houses were made fairly quickly, towards the beginning of the design process. It was decided that external materials were to be natural rather than manmade where possible and that they would be chosen for their longevity and performance as well as their appearance. The *Green Guide to Specification* (Anderson et al., 2002) and EcoHomes were the main reference points for the selection of materials. Materials and labour were sourced locally wherever possible. Hardcore from the site was recycled and a timber policy was developed, but apparently only the accreditation component of this policy was agreed to by the contractor.

The lessons inferred from the observation of the case-study design process in relation to building elements which could be useful in future low-energy and zero-carbon developments are four-fold. Firstly, an overarching guideline for selecting materials should be considered, such as making sure they are locally sourced. Secondly, detailed specifications for particular materials should be developed and communicated to all members of the project team. Thirdly, guidance should be used to inform material selection, but alternative materials not covered by such guides as the *Green Guide for Specification* (Ibid) should be considered, especially if they are recycled. Finally, materials and labour should be sourced as close to the development as possible, to reduce transportation costs and to support the local economy.

6.3 Water

Water use within households can vary dramatically, but in the UK the most common way of charging for water is by a standard annual charge which does not relate to actual consumption. Water use could be significantly reduced if households were charged in accordance with their water consumption (Warder, 1994). Water companies, at present, can choose whether to install water meters in new houses. The houses at the case-study development were all specified as having water meters. In the case-study development water use was looked at in design team and construction meetings, where two aspects of water were identified: rainwater harvesting and water consumption.

Water was discussed in the case-study design process from design team meeting 5 (Briefing) to construction meeting 9 (Decision meeting 3): a period of 20 months. Figure 6.3 shows when the two elements (rainwater harvesting and water consumption) of this theme were discussed. It also outlines the phases of the decision-making process, the first phase of which, identification, could be seen between meetings 5 and 11 (EcoHomes excellent). Development of possible solutions was undertaken between design team meeting 9 (Surfaces and finishes) and construction meeting 8 (Decision meeting 2). Selection was then undertaken from design team meeting 25 (Meeting with sub-contractors) to construction meeting 9. These phases are discussed in more detail in the following paragraphs.

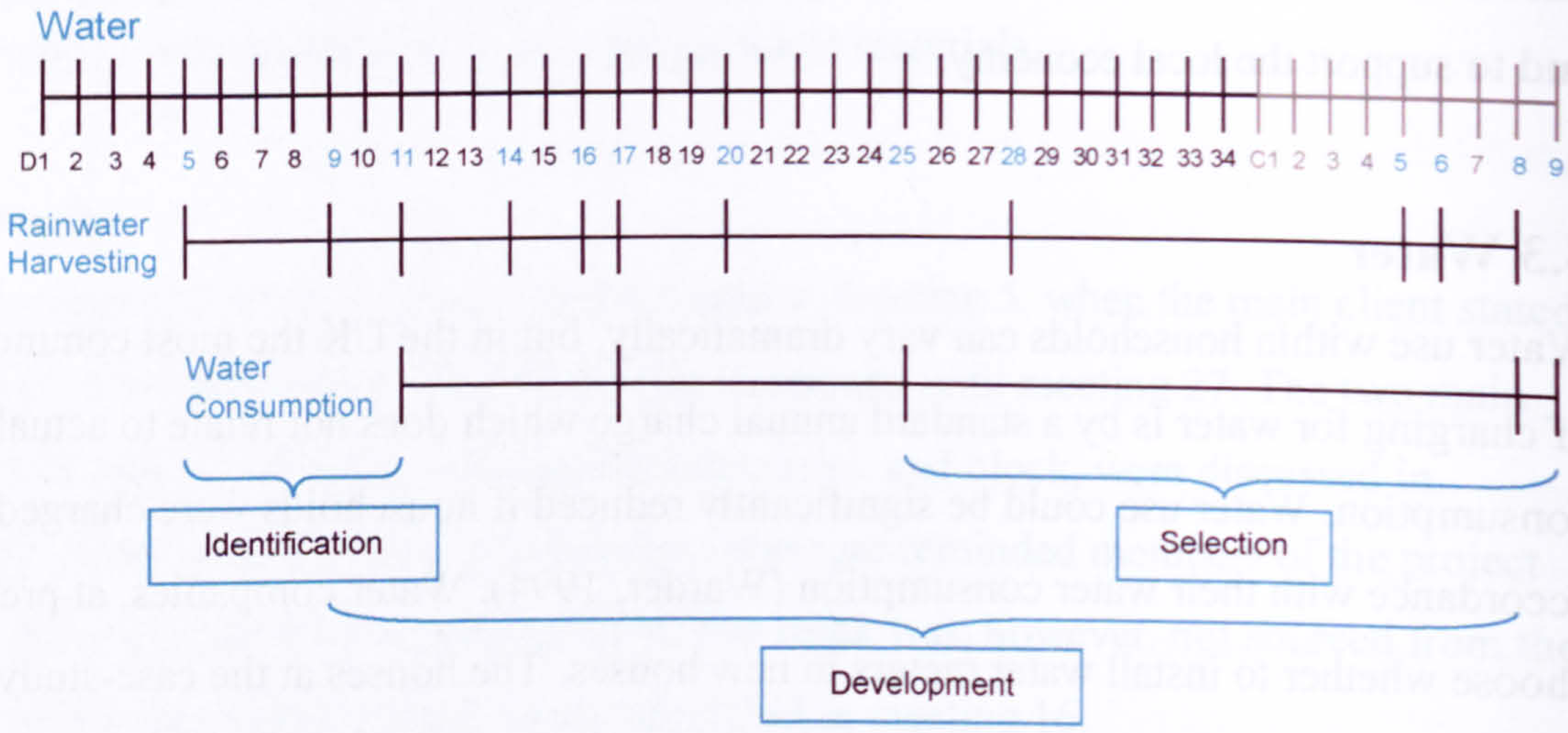


Figure 6.3: Time-line and phases of the decision-making process for aspects of water

6.3.1 Rainwater harvesting

Rainwater harvesting in the case-study houses was discussed between design team meeting 5 and construction meeting 8. The decision was identified in design team meeting 5, when it was stated in the design brief that all properties were to have their own rainwater harvesting systems, which would be used for flushing toilets, washing machines and external taps. Alternatives were developed from design team meetings 9 to 28 (Decision making to get to cost certainty), with meeting 11 being particularly significant in the decision. In this meeting the project manager was keen to "look at cost effective ways of doing this", which related to the EcoHomes credit for reduction of surface runoff. The M&E consultant was very keen to have a full rainwater recycling system incorporated into the houses, but this was challenged by the project manager who asked whether it was a first principle and argued that if it was not, they should come back to it if money was available later. The main client seemed to want some sort of rainwater harvesting system, but thought that this could come in the form of a simple water butt in the garden, rather than an integrated system. In meeting 20 (Infrastructure) the project manager stated that rainwater harvesting was to be an option for residents and so could not be relied upon to reduce surface runoff. The infrastructure and structural engineer stated that to reduce rainwater runoff from rainwater harvesting, all water would need to be collected from the roofs and stored centrally. He did not seem to think that single-plot systems would be adequate. The main client was not satisfied with this solution as he stated that there would be "water wars" if residents had to share stored water. In meeting 28, the contractor enquired whether rainwater butts would be supplied. This was agreed to by the project manager as it would get the EcoHomes credits needed. In construction meetings 5 (Progress meeting 4), 6 (Decision meeting 1) and 8, the water butt to be supplied to each house was specified and there was also discussion about recent reductions in costs for integrated rainwater harvesting systems, which were to be investigated for future phases of the development.

6.3.2 Water consumption

Water consumption in the case-study houses was discussed from design team meeting 11 to construction meeting 9. The issue was identified in meeting 11 (EcoHomes excellent), as the related EcoHomes credits were being discussed. The M&E consultant had calculated the estimated water use for the houses as $43m^3$/bedspace/year, which included "all standard water saving features". This did not, however, include a 4/2 litre dual flush toilet, which was suggested by the author of the present thesis. The M&E consultant was concerned that "people expect 6/9 litre flush", but the principal architect argued that "if it works, it works". It was then decided by the M&E consultant that toilets would be 4/2 litres. Showers were specified to reduce the water use to below $30m^3$/bedspace/year so that extra EcoHomes points could be obtained. In meeting 17 (EcoHomes, procurement and tendering), however, this figure had been increased to below $40m^3$/bedspace/year, which reduced the number of points obtainable. In meeting 25, the decision to use dual flush toilets was confirmed, but the sub-contractors who were supplying the equipment agreed with the M&E consultant who thought that more water may be wasted as people would flush the toilets more than necessary. In construction meetings 8 and 9 an outside tap was specified and water reduction methods were to be sourced for the bathrooms.

6.3.3 Conclusion

The selection of systems to reduce water use in the case-study houses was influenced by EcoHomes credits and requirements laid out in the design brief. The full, integrated rainwater harvesting system was a requirement of the design brief, which the M&E consultant was keen to implement. This was, however, not included as the project manager did not see this as a key objective and the main client compromised by adding a water butt in the garden that would obtain one EcoHomes point. Targets set for water consumption seemed to be variable, starting with $43m^3$/bedspace/year, falling to under $30m^3$/bedspace/year and then rising again to $40m^3$/bedspace/year.

The lessons inferred from the observation of the case-study design process in relation to decisions surrounding water for future low-energy and zero-carbon housing developments are three-fold. Firstly, an integrated rainwater harvesting system should be considered and discussed early on in the design process so that it can be incorporated into the house design. Secondly, if an integrated system is not possible then at very least a water butt to collect rainwater should be supplied to reduce the amount of drinking water that is used to water the garden. Finally, water consumption should be reduced as much as possible and all easy water saving measures should be taken (e.g. specifying low-flush toilets and non-power showers).

6.4 Building elements

Building elements form the main components of any building, and in this section are grouped under three categories:

- Windows
- Construction elements
    - Damp proof course (DPC)
    - Floors
    - Lintels
    - Rainwater goods
    - Structurally insulated panels (SIPs)
    - Wall ties

- Wiring
- Finishes

These elements made up a significant proportion of the materials used in the case-study houses and in this section the selection of materials for each element is discussed.

Building elements of the case-study houses were discussed from design team meeting 12 (Materials to be specified) to construction meeting 9 (Decision meeting 3), which represented just over 16 months of the design process. Figure 6.4 shows the meetings in which the three elements that make up this theme were discussed. The phases of the decision-making process are also shown. Identification was seen in design team meetings 12 and 13 (Risk workshop), development from meeting 16 (Drainage and EcoHomes) to 23 (Achieving cost certainty 3), and selection from design team meeting 24 (Detailed specification) to construction meeting 9. This indicates that only a short period of the design process was taken up identifying and developing material choices for the building components. These phases are examined in the following paragraphs.

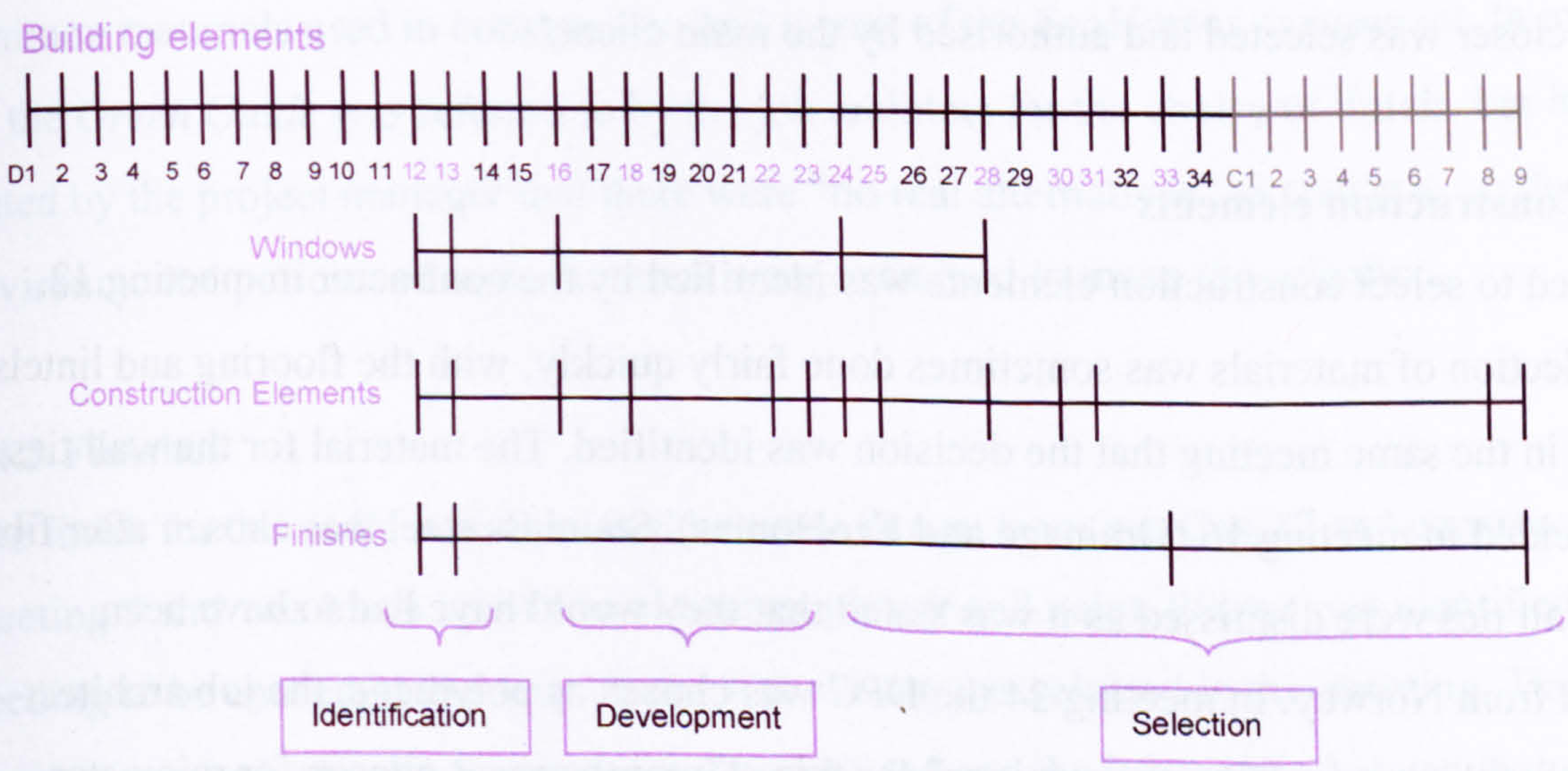


Figure 6.4: Time-line and phases of the decision-making process for the building elements

6.4.1 Windows

The windows for the case-study houses were discussed between meetings 12 and 26 (Ground works). Timber was selected for the window frames in design team meeting 12, which was the same meeting in which there was an identification of the need to choose a material. Pilkington was selected as the supplier of the windows in meeting 12, but by meeting 24 Saint Gobain had been chosen because they offered a good deal with a glazing U-value of 1.3 W/m^{2}K and passed 'Secure by Design' (Association of Chief Police Officers, undated) criteria (a safety standard for windows and doors). The windows were bespoke, with the glazing put in under factory conditions. The selection of a cavity closer for the windows was also identified in meeting 12. This was used to fill the cavity in the envelope of the house where the window was inserted. This cavity closer was specified as being plywood, but the contractor, in meeting 24, was keen to "do it with something else" and suggested uPVC and justified this by saying that the DPC was PVC. He was corrected by the job architect who stated that the DPC was in fact polythene and that there was no choice in that situation. The reason the contractor wanted another material was stated later in meeting 24, when he said that plywood could cost an additional "£500 a house; we need to think about the drivers". A compromise was reached in meeting 28 when a Rockwool cavity closer was selected and authorised by the main client.

6.4.2 Construction elements

The need to select construction elements was identified by the contractor in meeting 12. The selection of materials was sometimes done fairly quickly, with the flooring and lintels chosen in the same meeting that the decision was identified. The material for the wall ties was decided in meeting 16 (Drainage and EcoHomes). Stainless steel was chosen after fibre glass wall ties were dismissed as it was stated that they would have had to have been shipped from Norway. In meeting 24 the DPC was chosen as polythene, the job architect stating that there were "no other options" for this. Aluminium was chosen for rainwater goods, which were said to be the "most effective" by the contractor. Aluminium was seen by the project manager, in meeting 24, as the "cheapest option to meet green guide spec". Timber was considered to be the material with the lowest environmental impact, but due to its cost it was not selected. SIPs, prefabricated composite insulated panels used for quick, accurate construction, were explored as an option in meeting 31 (Progress update), but were ruled out because, according to the contractor, using the existing house designs meant it did not "stack up structurally". SIP construction was only explored towards the end of the design process, with the project manager saying in meeting 30 (Resolving issues to get to construction) that they "couldn't change the benchmark at the beginning, but now we have costs we can look at the potential that we thought about before". If the contractor had been involved earlier in the process, with more influence over the house designs, SIPs may have been used.

Non-PVC wiring was selected for the houses in construction meeting 8, after much deliberation about the cost implications. In meeting 22 (Achieving cost certainty 2), the contractor inaccurately stated that this would cost an extra £500 per house and seemed to think that it was ridiculous to even consider non-PVC wiring. The cost was actually only £100 more, which the main client decided was worth paying to significantly reduce the use of PVC. The choice of lintels and rainwater goods was influenced by the *Green Guide for Specification* (Anderson et al., 2002), which rates the environmental performance of common materials used in construction and is part of the EcoHomes assessment. In meeting 12 the *Green Guide* was referred to by the job architect for the choice of lintels, but it was stated by the project manager that there were "no real alternatives" to concrete, so the environmental policies of manufacturers were examined to make the selection.

6.4.3 Finishes

The finish for the walls was discussed between design team meeting 12 and construction meeting 9 and was made up of two elements, plaster and paint. Plaster was identified as needing to be chosen in meeting 12 and wet plaster was selected in this meeting. The contractor asked why dry lining was not being used and the job architect stated that wet plaster was used due to the thermal mass that it would provide and referred to the *Green Guide for Specification* (Anderson et al., 2002) as justification of this choice. The contractor expressed his concern in meeting 33 (Actions to get on site) about shrinkage cracks due to wet plastering, but it was confirmed in construction meeting 9 that wet plaster was to be used. Paint selection was only mentioned in two meetings, the first, meeting 12 when it was stated by the project manager that the second client was to create a paint specification. It was then not referred to again until construction meeting 9 when the author of the present thesis asked about the specification. The main client replied that it was "water-based, low-odour" with the option of being allergy-free.

6.4.4 Conclusion

This section has looked at the selection of building elements for the case-study houses. Most of the materials chosen for these elements have a lower environmental impact than those that are conventionally used. This was the case for: the timber windows; non-PVC wiring; rainwater goods; and paints. Some compromises were made during the design process due to cost implications, which included changes to wall ties and rejection of SIP construction. The contractor showed his lack of knowledge of the costs of non-conventional low-impact materials. For example, he suggested that the non-PVC wiring would be £500 more per house, when it was actually only £100 more. The contractor also questioned many of the suggested materials, such as the wet plaster and the cavity closer. These selections were justified by the job architect usually for environmental reasons. The *Green Guide for Specification* (Anderson et al., 2002) was referred to for some decisions, but others were made on the basis that the solution was apparently obvious without references to any source, because no choice was perceived.

Lessons inferred from the observation of the case-study design process in relation to building elements are five-fold. The first is that an environmental specification for building elements needs to be set early on in the design process. This should be informed by guidance, such as the *Green Guide for Specification* (Ibid). The specification, once defined, should be defended by those who make the decisions. Secondly, cost of building elements with lower environmental impact needs to be explored, as the contractor may have misconceptions about these costs. Thirdly, specifications that are challenged need to be justified by the person who made them in the first place. This means that decisions to substitute items should be discussed with those who made the specification. Fourthly, the principles of the project need to be referred to throughout the process of selecting building elements and finally, if SIP construction is to be used then it needs to be explored very early in the design process, when the designs are being created.

6.5 Insulation

Thermal insulation incorporated into external walls, roofs and floors of a house dramatically reduces the rate of heat loss and therefore reduces energy consumption significantly. Insulation can also be used to provide acoustic insulation and is used in internal walls to stop sound transmission between rooms and adjoining houses.

Insulation for the houses at the case-study development was discussed from design team meeting 11 (EcoHomes excellent) to 28 (Decision making to get to cost certainty), which represented nine months of the design process. Figure 6.5 shows the design team meetings in which insulation was discussed and shows the three elements that contributed to the insulation theme, identified from the data: specification of the insulation, acoustic insulation and cost. Figure 6.5 also shows the phases of the decision-making process for these elements. Identification of the decision took place in meeting 11. Development was undertaken between design team meetings 12 (Materials to be specified) and 24 (Detailed specification), with selection of a suitable solution agreed in meeting 28. These phases are discussed in more detail in the following paragraphs.

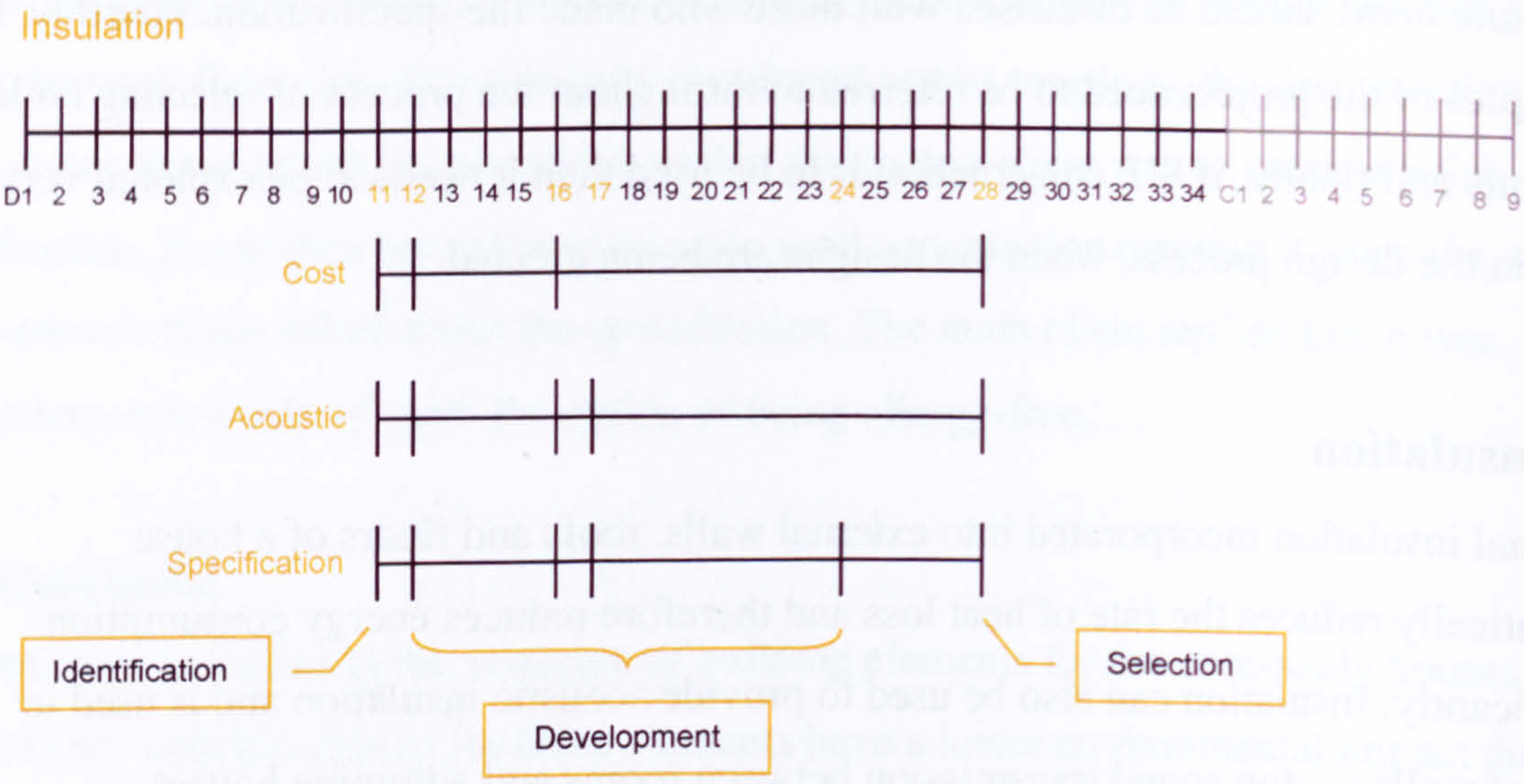


Figure 6.5: Time-line and phases of the decision-making process for insulation

6.5.1 Cost

Cost implications of insulation were first addressed in meeting 11, when the project manager stated that "if it is relatively cheap to achieve a higher standard then this will be exceeded". The EcoHomes credit that this relates to is the CO_2 target of 27 kg/m^2/yr, which equates to six EcoHomes points. In meetings 12 and 16 (Drainage and EcoHomes), cost versus performance graphs were discussed and these formed the basis of the decision being made, as it was felt that going any further was not beneficial as costs increased rapidly for little extra performance. This would also have meant expanding the cavity, which would have meant that the contractor would have had to work in an unfamiliar way, which could have caused large cost increases.

6.5.2 Acoustic insulation

The need to establish levels of acoustic insulation was identified in meeting 11 when the relevant EcoHomes credit was discussed. It was decided in this meeting, by the project manager, that the minimum points were to be achieved "until information to see how far you can go on at what cost" was obtained. This was confirmed in meeting 12 and then was discussed further in meeting 16, when the second client stated that above maximum points was "an achievable target" and that this would give "added value", whereas the job architect felt that acoustic insulation "is not that positive a gain". In this meeting it was decided that three points out of four would be earned, which equated to committing to pre-completion testing to improve performance by 3dB on Building Regulations Approved document E (BRE, 2005). In meeting 28 this was increased to 5dB to score four EcoHomes points.

6.5.3 Specification

The specification for the insulation was discussed between meetings 11 and 28, and the need for this discussion was identified in meeting 11 when the EcoHomes excellent credits that referred to insulation were discussed. It was decided in this meeting, by the project manager, that in relation to insulation and EcoHomes they could not "do anything other than full points; this is a given". This was developed through meeting 12, when the project manager stated that a cost matrix was to be created to compare cost and performance of insulation to make sure that the amount chosen was economically viable. In meeting 16 the decision was made to use 150mm of insulation to fill the cavity walls. This was a very significant point in the decision, as 150mm of insulation was 50% better than Building Regulations and was seen as "sensible" by the project manager. He stated in meeting 16 that "it does not cause too many implications as the cavity is the same". In this meeting the job architect also stated that "beyond 150mm the expense is too high for the performance gain". He also specified the type of insulation to be used: Rockwool and Kingspan. In meeting 24 the contractor was keen to substitute the chosen insulation so that he could investigate less expensive options. He was not allowed to do so because the specification for the insulation was set and the rest of the project team were satisfied with the selection made. The contractor seemed satisfied with having to fill the cavity as he said in meeting 28 that "it makes things easier as then we can't put the wrong stuff in". The second client, in meeting 16, expressed an interest in using Thermo-fleece, a product made from sheep's wool. This was not explored as an alternative as it was felt that it would be too expensive for the same performance given by other products. The project manager made the decision to use 150mm of Rockwool and Kingspan in the external walls, which was confirmed in meeting 28, as it was economically viable and would score highly on EcoHomes.

6.5.4 Conclusion

The specification of the insulation, both acoustic and thermal, used in the case-study development was driven by the need to achieve EcoHomes excellent; the overarching environmental standard for the houses. This set out several criteria that applied to insulation for the houses. The U-value specified for thermal insulation used in the walls was 50% better than Building Regulations in terms of reduction of heat loss and maximum credits were scored as this represented a significant increase on the EcoHomes maximum of 15% more. Acoustic insulation was specified so that it would meet the highest EcoHomes standard, although this was not decided straight away as some parties did not think it was as important as thermal insulation. It was, however, very important to the second client and the board of the case-study development.

The lessons inferred from the observation of the case-study design process for future developments in relation to thermal insulation are becoming increasingly important, especially as the UK aims for zero-carbon houses (HM Treasury, 2006). It is financially beneficial to reduce the energy needs of houses as much as possible so that any renewable energy capacity needed is as small as possible. Thermal insulation will contribute significantly to this, as a very well insulated house will only need a small amount of space heating, if any. Three lessons for future developments are apparent. Firstly, alternative insulation materials need to be looked at early in the selection process and all cost, performance and other information needs to be provided. It is useful to be aware that some benefits of using alternative insulation are not easily quantifiable (e.g. health and embodied energy), which is often a difficulty when comparing products. Secondly, cost and performance need to be analysed as there will be a point at which extra insulation is not economically viable, as a large increase in thickness eventually only provide a very small performance gain. Finally, if conventional masonry building techniques are to be used, the cavity of the walls should be filled with insulation to achieve the optimum efficiency. It would be possible to increase insulation levels in walls by using alternative construction techniques. It was stated by the project manager that if conventional masonry construction was used to increase insulation levels it could become unstable and the contractors would need to adopt a different way of building if the walls were widened to allow additional space for insulation.

6.6 Lighting

Lighting accounts for, on average, six percent of CO_2 emissions in UK houses (DCLG, 2006). Although this is a small proportion, it could be reduced further by increasing the use of low-energy light bulbs and LEDs (light emitting diodes). To minimise the use of electrical lighting, daylighting should be optimised.

Lighting for the houses at the case-study development was discussed from design team meeting 11 (EcoHomes excellent) to construction meeting 8 (Decision meeting 2), which represented 16 months of the design process. Figure 6.6 shows the meetings in which this theme was discussed, as well as showing the two elements of this theme: daylight and electric lighting. The phases of the decision-making process are shown, with identification taking place in meetings 11 and 13 (Risk workshop), development in meeting 13 and selection from design team meeting 16 (Drainage and EcoHomes) to construction meeting 8. This illustrates that the discussion surrounding alternative lighting solutions was limited and that a decision about what approach to use was reached quickly. Selection did, however, take a long time due to reconfirmation of the chosen approach. These phases are discussed in more detail in the following paragraphs.

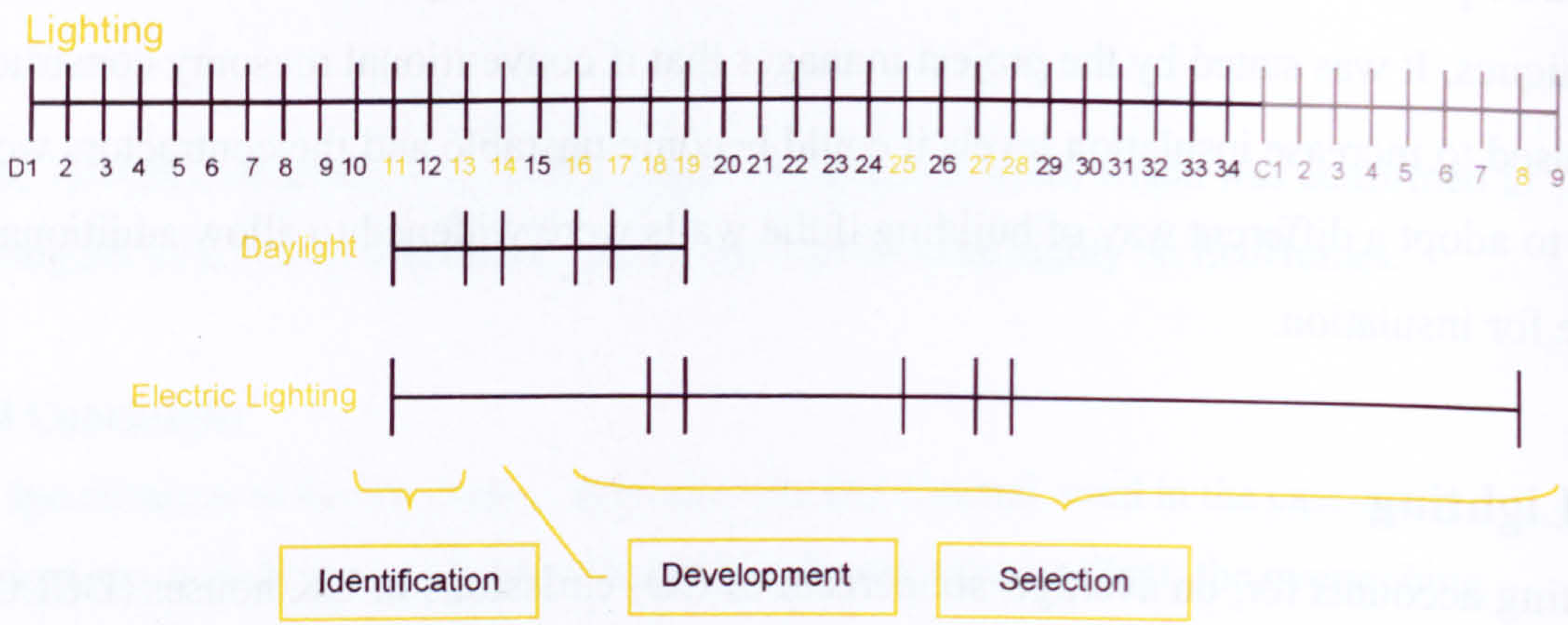


Figure 6.6: Time-line and phases of the decision-making process for lighting

6.6.1 Daylight

Daylighting in the case-study houses was identified in meeting 11, when it was noted that the EcoHomes credits relating to this feature were not being achieved in some rooms of some house types. The principal architect stated that, if this was the case, they would need to "change the design if there was not adequate light in all rooms". The M&E consultant agreed with this and supplied lighting diagrams to illustrate that luminance levels from daylight in some of the rooms was not adequate (doc.13). It was agreed in meeting 13 (Risk workshop) that minor amendments would be made to the designs if required. This was put into place in following meetings by increasing the size of several windows to meet the EcoHomes excellent criteria. In meeting 16, the job architect suggested that as well as resizing some of the windows, some of the rooms should be renamed to meet the daylight compliance targets set. In meeting 17 (EcoHomes, procurement and tendering) it was stated by the M&E consultant that "all house types meet all requirements for maximum EcoHomes credits".

6.6.2 Electric lighting

To choose the specification for the electrical lighting EcoHomes was the initial starting point. This issue was raised in meeting 11. The project manager, in this meeting, stated that "maximum points" would be met and the principal architect joked that the M&E consultant would "be sacked if this is not achieved". To meet the EcoHomes criteria and the objectives of the project, it was decided in meeting 18 (M&E drawings 1) by the third architect, who was the EcoHomes advisor for the development, that all light bulbs would be compact fluorescents. This decision was confirmed in the rest of the meetings that referred to electric lighting, with a lightings extra package, which would include a choice of light fittings for buyers, being suggested in meeting 25 (Meeting with contractors) by the project manager. The aim of this was to provide a choice of lighting for buyers, including a "VIP package" with low-energy lighting options. It was agreed by the project manager in meeting 25 that "many people will remove the original lighting fittings", so this option would reduce this waste as they could choose fittings that they wanted at the outset. The M&E consultant agreed that this was a good idea and that some other developers used this approach. LEDs were mentioned in meeting 28 (Decision making to get to cost certainty) by the main client, but were not investigated.

6.6.3 Conclusion

Selection of lighting elements for the case-study houses was driven by the objectives of the project and the EcoHomes standard. The EcoHomes standard dictated the minimum criteria to be met by the houses in relation to the daylighting in specific rooms and the specification of the electric lighting. The daylighting standard was achieved by minor changes to the design. The electric lighting specification was achieved by providing compact fluorescent light bulbs in all fittings and optional extra low-energy upgrades to try to encourage buyers to keep low-energy fittings. No alternatives to compact florescent light bulbs were discussed in any depth.

The lessons inferred from the observation of the case-study design process in relation to lighting that could be useful for future low-energy and zero-carbon developments are two-fold. Firstly, daylighting should be considered and maximised in all rooms from the beginning of the design process. Finally, light fitting options that include all low-energy light bulbs should be provided to encourage people to keep the light bulbs provided and not replace them with halogen bulbs that can use 50W each and often have three or four per fitting.

6.7 Heating and hot water systems

Gas used to fuel heating and hot water systems used in houses accounts for over 70% of UK domestic CO_2 emissions: 53% for space heating and 20% for water heating (DCLG, 2006). These are the largest sources of CO_2 emissions in UK houses. Therefore the systems have a great impact on final CO_2 emissions.

The heating and hot water systems were discussed from design team meeting 5 (Briefing) to construction meeting 9 (Decision meeting 3), which represented 19 months of the design process. Figure 6.7 shows the design team and construction meetings during which this theme was discussed. This time-line also shows the four elements of the heating and hot water systems identified from the data, each of which influenced the choice of system. These four elements are: the shower, the system, the boiler and the fire. Figure 6.7 shows the phases of the decision-making process for these elements. This indicates that the issues were identified between design team meetings 5 and 23 (Achieving cost certainty 3), developed between design team meeting 9 (Surfaces and finishes) and construction meeting 9, and then the selection was made between design team meeting 25 (Meeting with sub-contractors) and construction meeting 9.

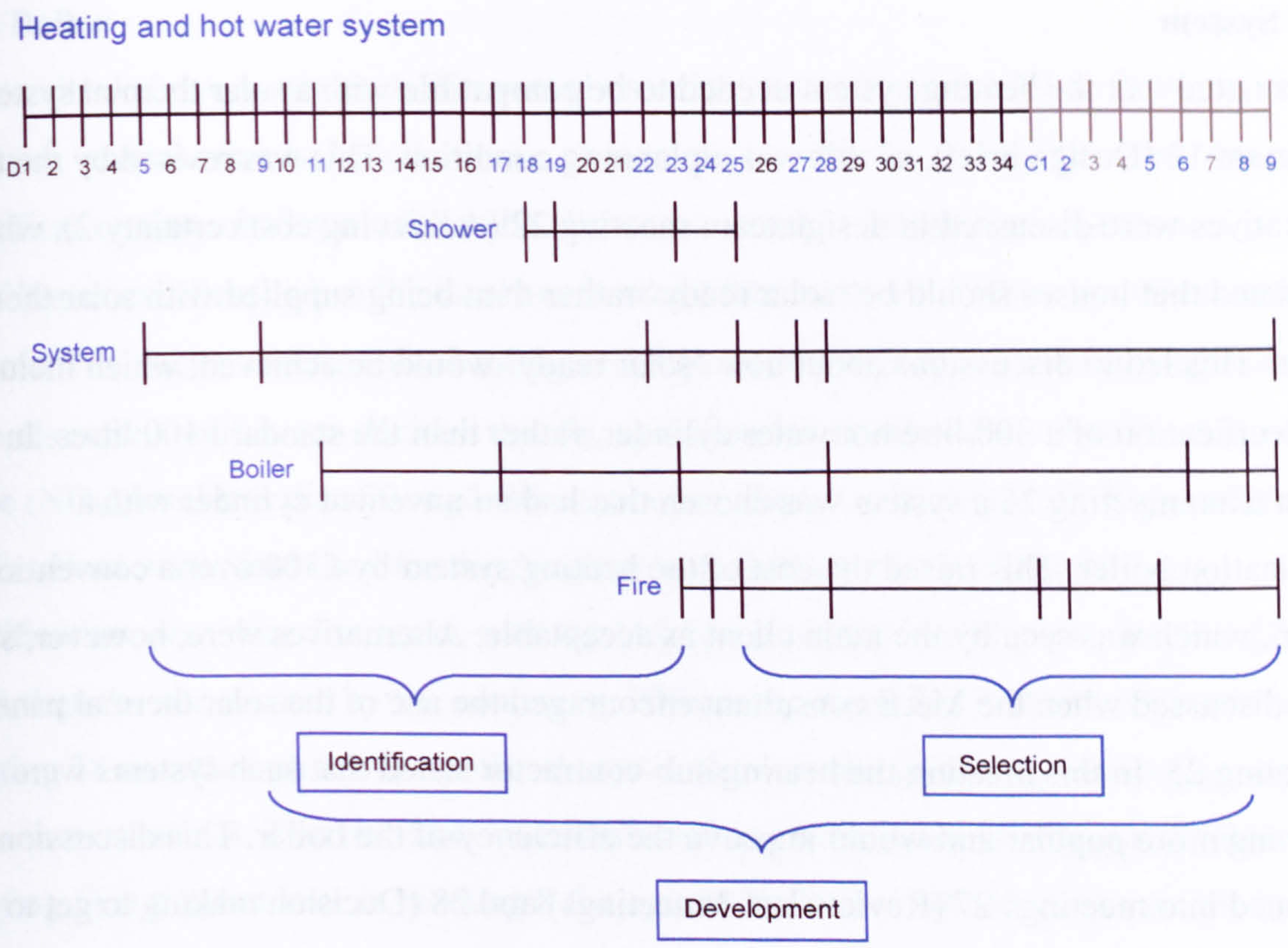


Figure 6.7: Time-line and phases of the decision-making process for the heating and hot water system

6.7.1 Shower

The showers for the case-study houses were discussed between design team meetings 18 (M&E drawings 1) and 25, as shown in Figure 6.7. Design team meeting 18 saw the identification phase of the decision, when the project manager questioned whether the showers were to be electric. This was discussed and developed in this meeting and in meeting 19 (M&E drawings 2), where several alternatives to the electric showers were identified. These alternatives looked at how the shower would work with various boiler and cylinder arrangements, which were presented by the M&E consultant. The electric shower was replaced by a conventional one that ran off a combination boiler to reduce CO_2 emissions from the reduction in electricity use. This decision was made in meeting 23 by the contractor and then confirmed in meeting 25.

6.7.2 System

It was noted that the heating system needed to be compatible with a solar thermal system in document 12 (Design brief), as this was a planning condition. This was revised by the time alternatives were discussed in design team meeting 22 (Achieving cost certainty 2), when it was stated that houses should be 'solar ready' rather than being supplied with solar thermal panels. This led to discussions about how 'solar ready' would be achieved, which included the specification of a 300 litre hot water cylinder, rather than the standard 100 litres. In design team meeting 25 a system was chosen that had an unvented cylinder with a combination boiler. This raised the cost of the heating system by £300 over a conventional system, which was seen by the main client as acceptable. Alternatives were, however, still being discussed when the M&E consultant encouraged the use of the solar thermal panels in meeting 25. In this meeting the heating sub-contractor stated that such systems were becoming more popular and would improve the efficiency of the boiler. This discussion continued into meetings 27 (Review last 3 meetings) and 28 (Decision making to get to cost certainty), with the idea being developed and explored. In construction meeting 8 (Decision meeting 2) the most significant stage in the decision occurred, when the heating sub-contractors stated that the specified system chosen would not be 'solar ready' as hoped. They went on to suggest using a system boiler with an unvented twin coil cylinder. A system boiler is similar to a regular condensing boiler but "many of the major individual components of the heating and hot water system are built in, which means that installation is quicker, neater, easier and more efficient" (Worcester, 2007). It also "includes an expansion vessel so there is no requirement for a feed and expansion tank in the loft which allows the installation to save space" (Ibid), although this would be needed for solar thermal panels. The main client stated that his "gut feeling was to go with the system boiler" with the project manager agreeing that it "would be embarrassing if we had to retro-fit". The decision was finally made by the main client in construction meeting 9 when the system boiler was chosen so that houses could be 'solar ready'. Solar thermal panels were to be an optional extra due to expense of supplying the panels, but it was thought by the main client that he would be able to get a good deal to supply these at a reasonable cost to house buyers.

6.7.3 Boiler

As described above, a system boiler was chosen in construction meeting 9. There were, however, several other boilers that were chosen prior to this for various reasons. The identification that a boiler needed to be chosen occurred in design team meeting 11 (EcoHomes excellent) when the EcoHomes credit that related to boilers was discussed. Alternatives, such as community heating and expensive combination condensing boilers were discussed until it was decided that the specification for the boiler should have nitrogen oxide (NO_x) level less than 70 mg/kWh and boiler Class 5, which was the highest level on the EcoHomes standard used for the development. Boilers that would meet this specification were then discussed, with the M&E consultant choosing one that was £73 more than the one wanted by the contractor. This more expensive boiler was chosen in meeting 28 as, although it was not the cheapest, the manufacturer was able to give support that others were not. This decision was confirmed in construction meetings 6 (Decision meeting 1) and 8, but later in meeting 8 the system boiler was introduced as an alternative and chosen in meeting 9.

6.7.4 Fire

Secondary heating was to be supplied in some of the larger house types. This was in the form of a fire in the lounge which was identified in design team meetings 23 and 24 (Detailed specification). It was assumed by the contractor in meeting 25 that the fires were to be gas, but in meeting 28 this was challenged by the project manager stating that he was not going to "take away choices by fitting one particular type of flue". Construction meeting 1 (Pre-start construction meeting) saw the client request a wood-burning stove, with prices to be investigated. It was also pointed out in this meeting by the author of the present thesis that there was "no point in having a gas fire as the central heating will be more efficient" as gas fires can be as little as 20% efficient, whereas central heating can up over 90% (EST, 2006). The decision to have a dual-fuel flue was confirmed in construction meetings 2 (Progress meeting 1) and 5 (Progress meeting 4) and a wood-burning stove was chosen by the main client in construction meeting 9.

6.7.5 Conclusion

In this section the decision-making process undertaken at the case-study development to select the heating and hot water system has been discussed. This process had three phases as stated in the introduction to this section, but these did not always run in linear order. It was often the case, as described above, that a decision would be made and developed and then a different conclusion reached and a different solution selected. This was the case with the heating system and the boiler and was due to different influences being present at different times and new information being made available. This caused delays in the decisions being made. Although the selection of the heating and hot water systems were considered from early in the design process, core members of the design team were not able to make the decision themselves and external consultants were engaged in the process. This included the M&E consultants, but because they had specified electric showers the team had lost confidence in their ability to make suitable decisions and at the last minute took advice from the heating sub-contractors, who could have had other motivations for suggesting the system boiler, such as a deal with the manufacturer. It was clear that several influences were at work throughout this decision. The contractor was keen to see the price reduced, while the main client and project manager wanted an efficient system that was compatible with solar thermal panels. This was eventually achieved.

During the design team meetings there was no discussion about the controls to be used with the heating and hot water system, which can significantly affect the efficiency of the systems (EST, 2007b).

The lessons inferred from the observation of the case-study design process in relation to heating and hot water for future developments of low-energy and zero-carbon housing are three-fold. Firstly, the specification for the heating and hot water system should be set as early as possible and should be as efficient as possible, as it makes a large contribution to energy use in houses. Secondly, the objectives of the development need to be considered when looking at decisions such as this. Finally, when making a decision like this, detailed information about how the system works, its efficiency and its cost are necessary. This will enable all parties to make informed decisions, so that every point of view can be considered and evidence can be evaluated to make the most sustainable decision.

6.8 Renewable energy

Renewable energy systems for houses are likely to become much more common in the UK as we get closer to 2016, when all new housing will need to be zero carbon as discussed in Chapter 1 (section 1.2). At present, in some parts of the UK, developers are obliged to provide ten percent of energy from renewable energy sources on site. This started in the London Borough of Merton and has become known as the Merton Rule (The Merton Rule, 2007). Renewable energy systems were discussed during the case-study development's design team and construction meetings, but no minimum was required when the planning conditions were renegotiated to EcoHomes excellent. Newark and Sherwood District Council, the local authority for the case-study development, did not have a specific target for renewable energy contribution.

Renewable energy systems were discussed from design team meeting 5 (Briefing) to construction meeting 9 (Decision meeting 3), which represented 20 months of the case-study design process. Figure 6.8 shows the meetings in which renewable energy systems were discussed and illustrates the phases of the decision-making process for this theme. The identification phase is seen in meetings 5 and 11 (EcoHomes excellent), development from meetings 5 to 29 (Finance) and selection throughout; from design team meeting 5 to construction meeting 9. This indicates that although decisions were made early on in the process, they were reconsidered later.

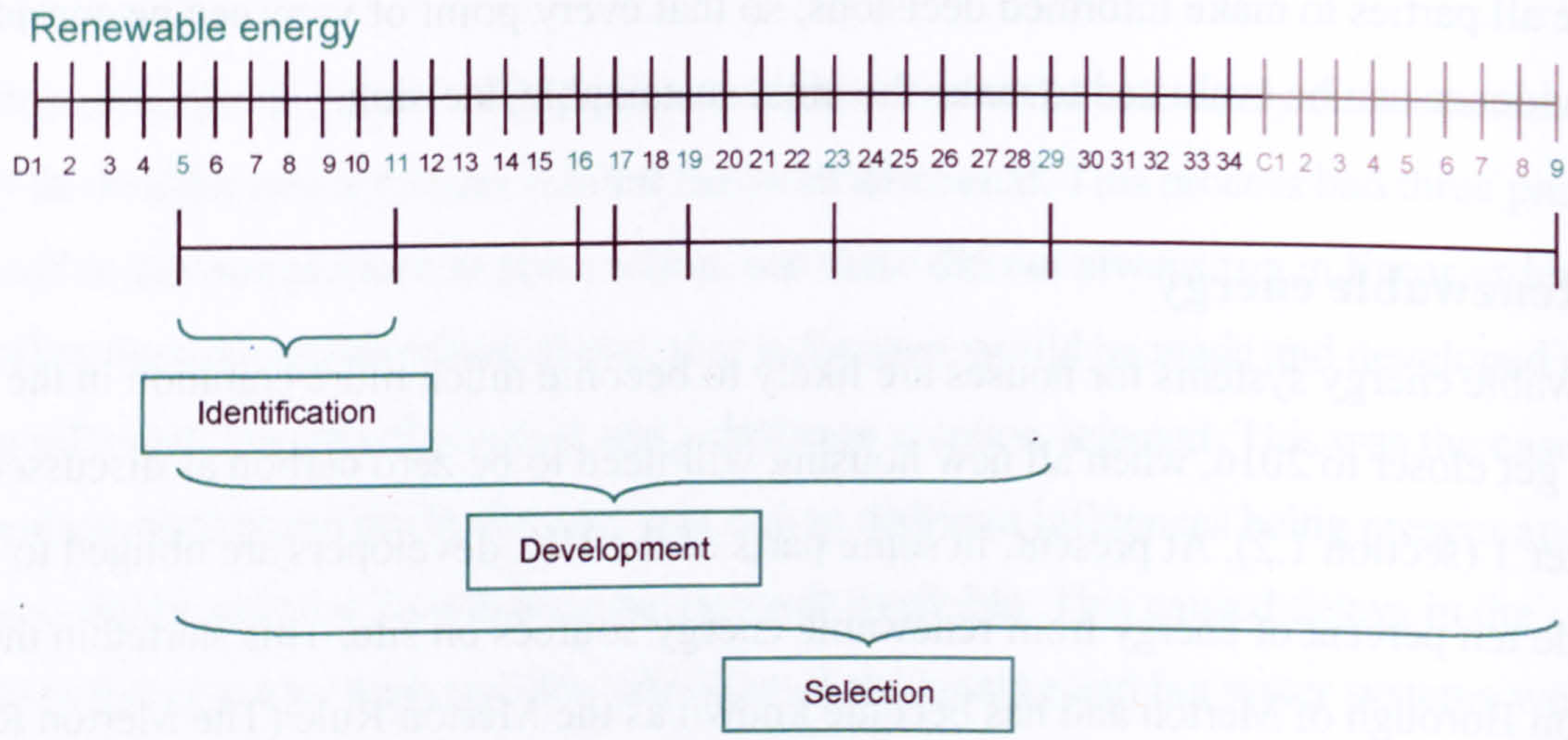


Figure 6.8: Time-line and phases of the decision-making process for renewable energy systems

Renewable energy systems were identified and discussed in meeting 5, as they formed part of the planning conditions for the development. These requirements included solar thermal hot water for all roofs facing south or up to 25° off south and ground source heat pumps to provide any heating that was necessary. Although this was the case, in this meeting the principal architect and the project manager stated that the design of the houses should not be over-reliant on renewable energy technology. Renewable energy systems such as photovoltaic (PV) cells, biomass and solar thermal were discussed in relation to one of the EcoHomes credits that related to supplying ten percent of energy use for the houses from a zero-emissions energy source. This discussion started in meeting 11 when both the M&E consultant and the project manager were certain that this credit could be achieved. In meeting 16 (Drainage and EcoHomes), however, the issue of money was raised by the project manager, but the main client was still keen to investigate this further as he felt that to meet the ten percent target, not much energy would need to be produced if the houses were super-insulated. By meeting 17 (EcoHomes, procurement and tendering), however, it was decided that no alternative energy sources were to be provided in the houses.

Nonetheless, options for renewable energy systems continued to be developed in meetings 19 (M&E drawings 2), 23 (Achieving cost certainty 3) and 29, but in construction meeting

9, it was stated that no renewable energy sources were to be provided in the houses. In meetings 16 and 19 there was a much more positive attitude to these technologies, largely from the M&E consultant. He was, however, not present in the later meeting when the decision not to include any renewable systems was made. This decision was due to the additional expense for these items and the financial situation in the first phase of the development. A cap had been placed on the amount that could be borrowed to fund this first phase by English Partnerships (EP). It was decided that the houses would be 'solar ready', meaning that all components of the solar hot water system would be in place apart from the solar panel. One of the larger house types was to be provided with a wood-burning stove in the lounge, but this was seen as additional heating rather than as a renewable energy technology.

This section has discussed the decision over whether renewable energy systems would be included in the case-study houses. Initially planning conditions required solar thermal and ground source heat pumps. These requirements were renegotiated so that no renewable energy systems were needed, but possibilities were still discussed for the EcoHomes assessment. In the end no renewable energy systems were included, although the houses were made 'solar ready' and wood-burning stoves were included in one of the six house types. Lessons inferred from the observation of the case-study design process about the inclusion of renewable systems are three-fold. Firstly, renewable energy systems should be discussed from the beginning of the design process and realistic targets set for their inclusion, which could mean achieving ten to twenty percent of the houses' energy needs and then finding the most effective way to achieve this. Secondly, detailed information about systems under consideration should be available to all members of the project team involved in the decision, so that an informed choice can be made. Finally, if no renewable energy system can be provided then it needs to be made as easy as possible for buyers of the houses to install systems at a later date.

6.9 Ventilation

The ventilation system used in a house can add to energy use and therefore heighten environmental impact, but some sort of system is necessary to achieve air-flow rates set in the Building Regulations.

The ventilation system to be used in the case-study houses was discussed from design team meeting 19 (M&E drawings 2) to construction meeting 9 (Decision meeting 3). This represented 12 months of the design process. Figure 6.9 shows the meetings in which this theme was discussed. These were towards the end of the design process and the decision was finally made in construction meeting 9. Figure 6.9 also shows the phases of the decision-making process: identification, development and selection.

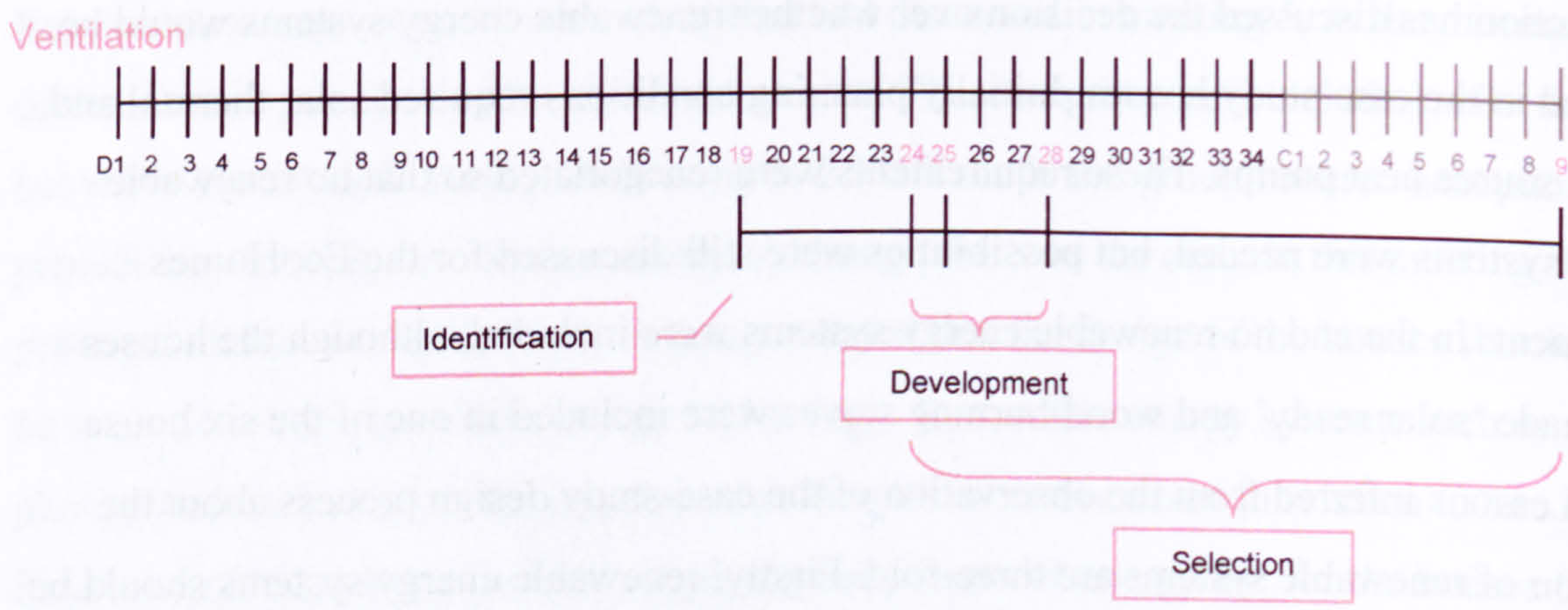


Figure 6.9: Time-line and phases of the decision-making process for the ventilation system

In design team meeting 25 (Meeting with sub-contractors), humidity fans were chosen to ventilate both the bathrooms and kitchens. These were, however, reconsidered later in the same meeting as more alternatives were suggested, such as heat recovery fans and standard fans, thus the development stage continued. Prior to the decision about what type of fan was going to be used there was a discussion, starting in design team meeting 19, surrounding the design of a passive stack system within the houses as the second client had found material that suggested this was the best option to "cut down on unnecessary electrical equipment". The passive stack approach was dismissed in design team meeting 24 (Detailed specification) when the job architect stated that "it was going to complicate the issue". This was confirmed in design team meeting 28 (Decision making to get to cost certainty) by the project manager, who stated that not having a passive stack system meant not having ducts which could cause health and safety as well as maintenance issues.

The question of what ventilation system to use was raised by the author of the present thesis in design team meeting 19, when she asked "are extractor fans in the bathrooms provided due to regulation?" This prompted a discussion about what type of ventilation fan could be used, with several alternatives being suggested, including a passive stack system by the main client. There was quite a long delay in making the final decision about the ventilation system as the standard fan that was eventually chosen was first mentioned in design team meeting 25. The most significant stage of the decision was when the contractor stated, in design team meeting 28, that the M&E consultants "didn't think humidity fans were a good idea", which led to the standard fan being chosen in construction meeting 9. Other factors that affected this decision were that this fan was what other developers used and that it was cheap. The decision was made by members of the core design team. The M&E consultants were involved in the early stages of this decision, but they were absent when the final decision was made. Each of the different parties involved had different objectives when selecting the ventilation system, with the two main drivers being cost, which was important to the contractor and the project manager, and environmental impact, which was important to the clients and the M&E consultants. The outcome of the decision may have been different if information was presented about the efficiencies and costs of different systems and if all members involved in making the decisions were present at all meetings.

This section has outlined the decision-making process undertaken at the case-study development to choose a ventilation system. This process had the three clear phases of identification, development and selection, although these did overlap somewhat as decisions were made and then alternatives were looked at and decisions reconsidered. The ventilation system was chosen towards the end of the design process, which meant that some options were no longer viable, such as passive stack.

The lessons inferred from the observation of the case-study design process in relation to the decision-making process surrounding ventilation for future developments of low-energy and zero-carbon housing are three-fold. Firstly, if the houses are to be ventilated using a passive stack, this needs to be incorporated in the initial designs for the houses. Secondly, the objectives of the development need to be considered when looking at decisions such as this, which was not always the case at the case-study development. Thirdly, when making a decision like this, detailed cost and efficiency information is necessary for all parties to make an informed choice.

6.10 Chapter conclusions

In this chapter decisions that affected the environmental impact of the houses have been reported. To conclude, time-lines of all the decisions explored are presented and discussed. Conclusions from the decisions are then drawn, followed by a summary of the lessons learnt.

Figure 6.10 presents time-lines for all the decisions that affected the environmental impact of the case-study houses. The diagram shows that there was a main period of discussion in relation to these decisions between meetings 11 (EcoHomes excellent) and 28 (Decision making to get to cost certainty), with five key meetings that addressed six or more of the decisions. These were: design team meetings 11, 16 (Drainage and EcoHomes), 17 (EcoHomes, procurement and tendering), 25 (Meeting with contractors) and construction meeting 9 (Decision meeting 3). Looking at the topics of these meetings, it is clear that EcoHomes had a large influence on decisions affecting the environmental impact of the case-study houses. Design meeting 25, in particular, saw many decisions being questioned and alternatives suggested. This is interesting as this was when these decisions were discussed with sub-contractors. Construction meeting 9 was when many decisions were finally confirmed, with some last minute changes being made without many members of the project team being present.

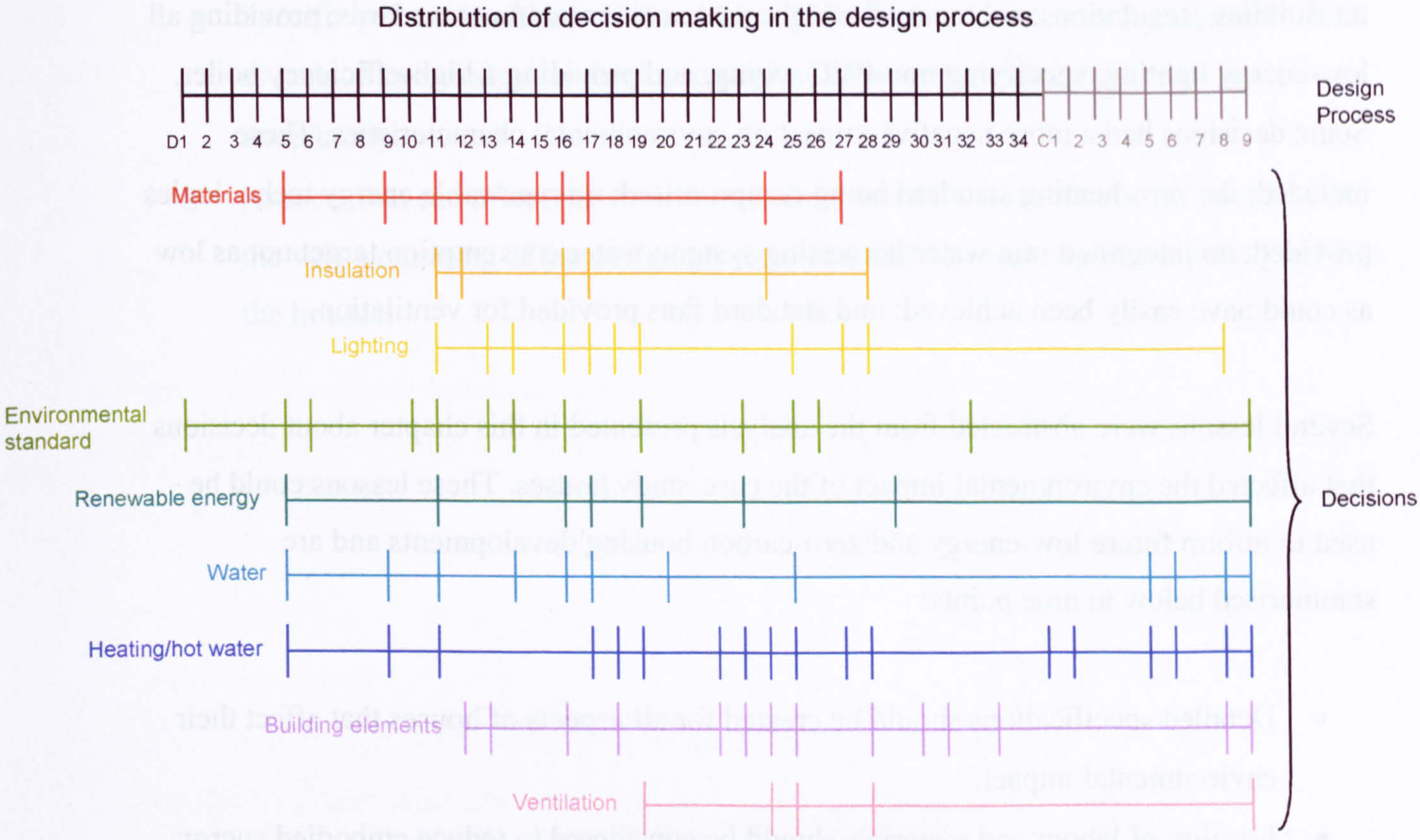


Figure 6.10: Time-lines for all decisions that affected the environmental impact of the case-study houses

This chapter has explored the decision-making processes for nine decisions that related to the environmental impact of the case-study houses. These decisions had several common themes running through them, including the drivers which influenced the characteristics of certain elements. The drivers used in the case-study design process to make these decisions were the EcoHomes environmental standard and the planning conditions outlined in the design brief for the project. The *Green Guide to Specification* (Anderson et al., 2002) was used as a reference source to guide these decisions. EcoHomes excellent was by far the most influential, with five out of the nine decisions (materials, insulation, environmental standards, water and lighting) being heavily influenced by it. The planning conditions were renegotiated early in the design process. Decisions that had a particularly positive impact on the environmental characteristics of the houses included: local sourcing of materials; creating a timber policy; recycling hardcore on site; improving the average U-value by 50% on Building Regulations; achieving the highest acoustic insulation standards; providing all low-energy lighting; specifying non-PVC wiring; and providing a high-efficiency boiler. Some decisions had a more negative impact on environmental characteristics. These included: the zero-heating standard being compromised; no renewable energy technologies provided; no integrated rain water harvesting system; water consumption target not as low as could have easily been achieved; and standard fans provided for ventilation.

Several lessons were abstracted from the analysis presented in this chapter about decisions that affected the environmental impact of the case-study houses. These lessons could be used to inform future low-energy and zero-carbon housing developments and are summarised below in nine points:

- Detailed specifications should be created for all aspects of houses that affect their environmental impact.
- Locality of labour and materials should be considered to reduce embodied energy.
- Knowledge of elements that affect environmental impact needs to be high for decisions to be made that decrease this impact. A wide variety of skills and knowledge from project team members is required for this to be successful.
- Alternatives for aspects of the houses should be investigated, with cost, efficiency and other benefits (such as health and embodied energy) presented.
- All decisions should be, if possible, discussed with members of the project team who have expertise in the particular area under investigation. If no member of the project team has expertise in that area, then an external party should be consulted.
- An overarching environmental standard should be created or chosen and adhered to by all members of the project team throughout the design process.

- The chosen environmental standard should be communicated to the entire project team, along with the objectives, drivers and principles behind the project, which should all be considered when making any decision that has implications on them.
- Specific prices should be obtained for aspects that the contractor is unfamiliar with, as lack of knowledge can lead to cost premiums being added to account for uncertainty.
- Aspects that can affect the environmental impact of houses should be discussed at the very beginning of the design process, as many elements need to be designed into the houses.

7. Professionals in the Design Process: their perspective

The members of the project team who are involved in the design process of a project make the majority of decisions within that process. These decisions dictate every aspect of the project. The more the members of the project team are involved in the process, the more influence that they have over the decisions, as they have more chance to state their opinions. This leads to key members of the project team making the majority of the decisions and being able to assert their influence. The influence exerted by any member of a design team may reflect their economic, social and environmental concerns; some much stronger than others. In this chapter the perceptions of key members of the project team towards economic, social, environmental and other issues in the design process are explored.

Members of the project team have been investigated in previous research which has referred to the design process, but most of this research focused on the architect's role. There is seemingly no research examining the attitudes and influences of project team members in relation to low-energy buildings. This chapter analyses interview data collected from key members of the project team at the case-study development. The methods used to collect and analyse the data for this chapter are described in detail in Chapter 4 (section 4.2, p.60). Template analysis was used to analyse the data collected from the interviews with project team members. The predefined themes were influenced by the interview questions and included: involvement of project team members; experience; key issues; environmental standard; design process; decision making; barriers; lessons; and the project team. Template analysis derived the following seven themes that are discussed in this chapter:

1. Elements of the design process
2. Project team knowledge and experience
3. Project team workings
4. Project team motivations
5. Environmental standards

6. Barriers and how to overcome them
7. Lessons

The members of the project team who were interviewed are presented in Table 7.1, with the specific group that they belonged to (as outlined in Table 3.3, p.54), a reminder of their role, the date on which they were interviewed and the length of the interview.

Role	Team			Date	Length (minutes. seconds)
	Core	Design	Construction		
Structural and infrastructure engineer		√	√	15/11/2006	91.23
Contractor			√	17/11/2006	55.15
3rd contractor			√		
Job architect	√	√		5/12/2006	43.54
Project manager	√	√	√	5/12/2006	40.54
Main client	√		√	16/1/2007	40.16
M&E consultant		√		18/1/2007	95.00
2nd client	√			13/2/2007	30.00

Table 7.1: Members of the project team interviewed

In this chapter the themes identified through template analysis are discussed in the following sections. Each contains a short introduction, a discussion of each of the elements that make up that theme, a conclusion, and a matrix outlining which members of the project team mentioned each element. The chapter is then summarised and concluded. The conclusions identify which professionals have a particular influence on specific aspects of the design process and what implications this had on the case-study houses.

7.1 Elements of the design process

This section discusses the attitudes of members of the project team towards elements of the design process. These elements were identified from the data and include the time scale of the process and two detailed design issues: renewable energy and components.

7.1.1 Time

The majority of the members interviewed (project manager, main contractor, architect, M&E (mechanical and electrical) consultant, main client and structural engineer) stated during their interviews that the design process at the case-study development had taken longer than expected. The job architect, M&E consultant and the main contractor stated how long they had been involved in the project for, these periods were three years, two and half years, and 18 months respectively. The job architect stated that if conventional developers had started the design process in 2003, they would have wanted to be on site in 2004. In relation to the length of the process, several members compared the case-study development to a conventional development. The job architect stated that "if we had got a conventional house builder then the profit would have been the key driver and it would have all been about how quickly can we secure planning permission and how quickly can we get to site". He continued by saying that the development took longer because the drivers were different. The main client compared the level of cost certainty (89%) obtained on the case-study development before going to site with that of conventional developments, stating that they "would go to build a lot earlier than that with a lot more preliminaries".

The reasons that members of the project team gave for delays were mainly based around the client's expectations. The architect stated that "getting it right and getting the development they wanted to see" took the extra time. This was expanded on by the M&E consultant who said that "time has been spent getting the standards, getting that balance between the original aspiration and the actual affordability right and so what will be delivered will be the right product". The project manager, however, quoted the reasons for the delay as being "unrealistic expectations on everybody's part", which refers in particular to the ambitious energy standard of zero-heating set at the very beginning of the project. It was fairly early in the design process that all parties agreed that this standard was unrealistic, which is why it was changed. There were several members, including the main client, second client and the M&E consultant, who thought that the development could go beyond EcoHomes excellent fairly easily, but this also proved to be unrealistic. The structural engineer referred to delays with designing the drainage on site.

7.1.2 Detailed design issues

During the interviews four detailed design components were discussed: wiring, boilers, bricks and structurally insulated panel (SIP) system. Wiring was discussed by the main client, who noted that the contractor had initially given an unrealistic quote for non-PVC wiring, which was later confirmed with the supplier as being £400 cheaper per house. Boilers were highlighted by the M&E consultant as a "big concern" as he was very worried that the contractors were going to "specify a boiler because they think they can get hold of it better, because it's cheaper" and stated that he felt it was vital to "force through the most important quality issue on an efficient housing project". The M&E consultant justified the boiler specified as being the best choice compared to that suggested by the contractor, as it was a very efficient boiler manufactured in the UK, which reduced the transportation energy associated with it. Bricks were discussed by the main client who stated that they were not being sourced from the most local supplier, but instead were being sourced from a supplier with a very energy-efficient plant that recycles its heat, which he felt was the most 'sustainable' choice. SIPs were discussed by the contractors who felt that this technique was no longer appropriate for the case-study development in this phase because "we were involved in the process a little bit too late". The third contractor expanded on this by saying that they would have had to be involved very early in the design process for SIPs to have been considered when the designs were being drawn up.

7.1.3 Renewable energy

Renewable energy technologies were discussed by some of the interviewees, with the main client the only one to mention more than one specific technology. The main client stated that the decision to put gas onto the site was something he was not entirely happy with. He said that he would have liked to rely on ground source heat pumps or biomass, but that he understood that the decision was a commercial one. The main client also discussed the fact that a wood burning stove was being included in one of the house types and that the main contractor "honestly thought it was a gas effect log fire". The main client observed that it was obvious from this that the contractor had not thought of it being anything else. The main client and the project manager both explained that solar thermal was to be an option on the houses, with the project manager explaining the choice between putting on solar thermal and making the house 'solar ready' as follows.

> Were we going to put solar thermal as standard, is the client going to pay? Or do we just ask the plumbing contractor to provide a twin coil cylinder that we could simply plumb to, with less disruptive costs if a prospective purchaser says 'I'll pay the extra'.

The M&E consultant seemed disappointed that no renewable energy technologies were incorporated in the houses and stated that "from our point of view those ideas and those initiatives have only gone so far because they've fallen down on simple affordability". He was, however, more positive about their inclusion in future phases of the development. The contractor stated that he would like to be involved in "developing the add-on things", referring to renewable technologies. He also stated, with reference to the four proposed earth-sheltered houses on site, that he thought it was "very exciting and would like these to take off so we can be involved".

7.1.4 Conclusions

In summary, several members of the project team expressed the view that the design process at the case-study development took a lot longer than expected, and longer compared to conventional housing developments. This was seen as being due to the fact that the project team, especially the client, wanted the project to be right in terms of the environmental standard as well as in affordability terms. Some detailed design components of the houses were of particular importance to individual members of the project team. The client was keen to use the most sustainable material for the wiring in the houses and to source the bricks from as sustainable a source as possible. The M&E consultant was keen that the boiler he had specified was used in the houses as he saw this as a very important element that should not be compromised on. The boiler and the wiring selection showed that there were cost issues and lack of understanding of the need to specify the most sustainable solution on part of the contractor. The contractor discussed the fact that SIPs were not included in any of the house designs as it was only considered towards the end of the design process. The main client, the M&E consultant and the contractor were interested in incorporating renewable energy technologies into the houses, but none were included in this phase due to their cost.

The matrix shown in Table 7.2 presents an overview of which members of the project team referred to particular elements in their interviews. It shows that it was only the second client who did not mention any aspect of the design process. The majority of members spoke about the length of the process, with both the job architect and M&E consultant mentioning all elements identified for this theme. The components mentioned were specific to an individual or, in the case of SIPs, an organisation. Renewable energy technologies were mentioned by the main contractor, project manager, M&E consultant and the main client, who each referred to three themes.

Theme (in bold) and elements	Project team member							
	Engineer	Main Contractor	3rd Contractor	Architect	Project Manager	Main Client	M&E	2nd Client
Time								
Longer	√	√		√	√	√	√	
Time scales		√		√			√	
Comparison				√		√	√	
Explanation	√			√		√	√	
Components								
Wiring						√		
Boilers							√	
Bricks						√		
SIP		√	√					
Renewable energy								
Gas substitute						√		
Biomass						√		
Solar					√	√		
Future		√					√	

Table 7.2: Elements of the design process referred to by project team members

7.2 Project team knowledge and experience

In this section the knowledge and experience of the project team with regard to low-energy buildings is discussed. Four themes, identified from the data on this issue are: knowledge; experience of low-energy housing projects; experience of projects on the case-study development; and experience of other low-energy projects. The project team members interviewed had a great influence on the outcome of the project, therefore their knowledge and experience of low-energy building design and construction was likely to be very important in achieving the desired outcome.

7.2.1 Knowledge

The project manager and the main client were the only two members of the project team who mentioned knowledge. The project manager stated that his "understanding of sustainable construction and green design and environmental technologies has increased ten-fold" due to his involvement in the project. He also admitted that he initially thought of 'sustainable construction' as a "bit of a band wagon and a few buzz words", but by the time of his interview he thought of it as "something more meaningful and more real and more worthwhile". The client did not refer to his knowledge, but commented on the increasing knowledge of the project manager and the main contractor. He stated that the main contractor was "starting to think in a different way" and that he had tried to get him to "think a little bit less traditionally". He referred to the project manager's understanding of the issues in relation to the selection of brick manufactures, stating that he had made an argument about embodied energy of the bricks from a more local source compared to a source that had a very efficient manufacturing process. The main client commented that "he would not have said that six months ago" and that "it's quite interesting to have sort of influenced that level of thinking".

7.2.2 Experience of low-energy housing

Three of the project team members interviewed stated that they had previous experience of working on low-energy housing projects. The job architect stated that he always tried to incorporate environmental strategies into his buildings, but that this was not always successful. He then went on to describe the most recent low-energy housing project that he had worked on, which was a one-off private house for a client with whom he had worked closely. The structural and infrastructure engineer explained that he was working on a low-energy housing demonstration project at Nottingham University (C60 project), where he was involved in the drainage for the site. He also commented that he had worked with several mainstream housing developers and that he believed that their view is that the current 'sustainability agenda' is "not moving in the right direction for them; it's not driven by what is important to them, no matter what they say". The M&E consultant explained that his involvement in low-energy housing projects had only been through working on the case-study development. He stated that his organisation was "looking at strategic energy solutions, sort of greening-up the standard building processes". He gave examples of large-scale projects being developed by private housing developers that he was working on to guide them towards the most 'sustainable' building engineering solutions. He explained the developers' motivations for being interested in sustainable solutions as "being able to build houses to generate the money in the first place. They're more concerned about being allowed to build that many houses in today's climate, so their thinking is that by sending the right messages for the planning process, that will help guide that through".

7.2.3 Experience of other projects on the case-study site

Several members of the project team who were interviewed had gained experience of low-energy projects from working on non-domestic buildings on the case-study development site, consisting of commercial and light-industrial units. The main client stated that he had been the client representative for the head quarters of the case-study development; a flag-ship building for the site. He said that this involved "ensuring that the vision for the development was included in the building". The project manager had also worked on this building as well as on his practice's offices, also on the site. He compared these two buildings, stating that his practice's office did not have "the bells and whistles on, but they do have the core low-energy usage, on the basis of rather than spending money on plaster for internal decoration we put the same amount of money into increasing the insulation levels". The third contractor also stated that his organisation had been involved in the development of the architectural practice's office as well as the first commercial building on the site.

7.2.4 Experience of other low-energy projects

The project manager, M&E consultant and structural engineer stated that they had previous experience of other low-energy buildings. The project manager did not refer to any examples that he had worked on, but did say that "increasingly over the last five years there has been a push towards, especially the last three years, a push towards reducing running costs". The M&E consultant gave two examples of low-energy commercial clients that he had worked with. In one of these examples he had looked at biomass and waste to heat incinerators. He also stated that he gave lots of practical guidance to clients, which was not as hands on as with some projects, but he was able to put proposals forward for systems that he thought would be appropriate with their relative costs and potential savings. The structural and infrastructure engineer gave an example of his work on a factory unit that was recycling rainwater for its industrial processes, making it "self-supported by rainwater and recycling of water". The main contractor stated that he had experience of creating low-energy leisure accommodation that was very challenging on time scales and budgets. Although the second client did not mention any experience of low-energy building projects, she gave details of her past experience giving advice to businesses to make them more environmentally aware. She described this as providing "practical and pragmatic environmental solutions to businesses".

7.2.5 Conclusions

Knowledge of project team members about elements that affected environmental impact of the houses was low at the beginning of the project and was not referred to by many members and it was only the project manager who actually stated that his knowledge had increased. The main client agreed with this, and also thought that the contractor had a new way of working that was more considerate of environmental issues. Low-energy housing projects had been worked on by a few of the project team, but none of these projects were large-scale. Most members had experience of working on low-energy buildings of some kind, with much of this experience gained at the case-study development site. The matrix in Table 7.3 presents an overview of which members of the project team referred to particular elements of knowledge and experience. The matrix shows that the elements were, on most occasions, discussed by only one individual and that experiences came from a variety of different types of building projects.

Theme (in bold) and elements	Project team member							
	Engineer	Main Contractor	3rd Contractor	Architect	Project Manager	Main Client	M&E	2nd Client
Knowledge								
Project Manager					√	√		
Contractor						√		
Experience of low-energy housing								
Recent private developments							√	
Demonstration project	√							
One-off house				√				
Case-study development								
Flag-ship HQ					√	√		
Practice offices			√		√			
First building on site			√					
Other buildings								
Leisure accommodation		√						
Commercial buildings	√				√		√	
Business advice								√

Table 7.3: Elements of knowledge and experience referred to by project team members

7.3 Project team workings

This section discusses how members of the project team perceived the relationships within that team. Three themes that related to this were identified from the data: role and responsibility of the members; the partnering process; and involvement of the members in the project, including how they were introduced to it. The relationships between project team members are very important to how the design process progresses. If members of the project team can work productively together this increases cohesion which is likely to enable them to deliver the project more efficiently.

7.3.1 Role and responsibility

Members of the project team were asked to give a brief description of their role and responsibilities in the project. The main client explained that his role involved "representing SEV and the board on the design team to ensure that the will of SEV is incorporated in the overall design of the housing scheme". This also included making sure that the vision and the end use were correct. The second client stated that she "kept an overview on the project" and that her role involved "policy development and keeping of the faith". The project manager described his role as having to do "what is necessary to facilitate a process or event happening" and stated that this begins with bringing the design team together and ends with the completed project. The project architect said that he was the "lead designer in terms of how everything looks and goes together, how the site works, how the buildings are designed".

The main contractor described his role as putting "together the preliminary costs in the form of work packages" and to "make recommendations to the design team on buildability and costs" and then to go through the process of "value engineering". The M&E consultant described his job as building services engineer as having to look at the "performance design of the mechanical and electrical services" which involved setting "the quality standards and performance spec" as well as being an energy advisor at a "strategic level to go through options". The structural and infrastructure engineer stated that he had "been responsible for the highways and drainage". Many of these roles are standard for a project of this kind, but it is the clients' roles which are of particular interest as they were acting as the protectors of the principles set at the beginning of the project. The input of the M&E consultant as an energy advisor was also crucial to the environmental aspects of the project.

7.3.2 The partnering process

The importance of partnering was only referred to by the main contractor. He stated that "the way this project has been procured has been in the very true spirit of partnering, so we've been open and honest". The main contractor described the fact that in the original concept for the project his organisation was "a partner in the scheme and we were going to share in the profit", but this changed over the course of the project. He stated that on this project everyone had been "partnering properly" and that "when we've been putting together the costs I've been totally truthful and I could have done certain things that would have increased our profitability, but I haven't done that". The main contractor apparently felt that he could trust everyone else to do the same and he mentioned, on several occasions, the need for trust. The main contractor explained that he needed to trust the other members of the project team as "if we hadn't had got the contract, in theory from a business point of view we would have been well out of pocket". He also stated that the project manager "wouldn't allow me to get my other colleagues involved", but because of the relationship between the two parties this decision was accepted. It seemed that the project manager did not want other members from the main contractor's organisation to be involved in the project as he felt that they may be able to influence the design process to suit their interest, which may have conflicted with those of SEV.

7.3.3 Involvement

Apart from the client, whose idea and vision the case-study development was, the contractor had been involved in the project for the longest period of time. The third contractor stated that he had heard "about what they were doing and at the time we were looking at SIPs and we wanted to do a housing forum demonstration project and that's how we first met up with the client". The third contractor explained that he had taken the clients on a tour of leisure accommodation that he was working on and that the clients were "impressed as that was all fast track, multiple units and I think that helped his vision of what he was trying to achieve". The project architect said that he was involved in the project from 2003 when he was asked by the contractor to prepare a "sketch strategy for how we would take the design forward". The project manager became involved just after that and stated that "when the design process starts very quickly there has to be a realisation and an understanding that what has been designed... can be delivered within cost parameters". The M&E consultant became involved in the project because "we were there at the right place at the right time and I think the reason for wanting to get involved is something which is a bit more than a standard housing development".

The involvement of members of the project team in the case-study housing development ranged from a year to over four years, with much of this involvement stemming from previous working relationships. The main contractor met the client in 2002 and introduced the client to the job architect and project manager a little after that. The contractor had worked with the architect and project manager on several previous projects, including the leisure accommodation described earlier as well as non-domestic buildings on the case-study site. The architect and project manager, who were involved in the houses from 2003, worked with the client on the client's head quarters after the introduction by the contractor. They had in turn worked with the structural and infrastructure engineer, who they introduced to the client to work on this project. The M&E consultant had also worked on the client's head quarters (to incorporate the various renewable energy technologies) and was involved in the houses when "they started getting everyone worked up about a scheme".

7.3.4 Conclusions

The roles held by the project team members who were interviewed represented a spectrum of responsibility. Each member had a unique role in the design process, but often responsibilities were shared, such as detailing costs, which was divided between the main contractor and the project manager. Partnering and trust were seen as very important to the main contractor, who seemed to be the one with the most to lose from any relationship breakdown. Until his organisation was under contract, it received no financial gain. Members were involved in the project at various times, with the longest, apart from the client, being the contractor. There was a history of working relationships between many parties involved in the project team, which seemingly helped parties to trust one another.

The matrix in Table 7.4 presents an overview of which members of the project team referred to particular elements of the project team relationships. The main contractor was the only member of the project team to mention all elements, and no one else mentioned partnering. The project manager and the M&E consultant were the only professionals not to mention introductions to other members.

Theme (in bold) and elements	Project team member							
	Engineer	Main Contractor	3rd Contractor	Architect	Project Manager	Main Client	M&E	2nd Client
Role and responsibility	√	√		√	√	√	√	√
Partnering								
Partnering		√						
Trust		√						
Open discussions		√						
Involvement								
Involvement	√	√	√	√	√		√	
Introductions	√	√	√	√				

Table 7.4: Themes and elements of the workings of the project team referred to

7.4 Project team motivations

In this section the motivations expressed by the members of the project team during their interviews are discussed. These include both 'internal' motivations that reflect their own perceptions and 'external' motivations which reflect their perceived motivations of other members of the team. These motivations, identified from the data, were grouped under 14 categories: cost, environmental impact, vision, interest, aesthetics, quality, pride, demonstration, getting to site, time, locality, best techniques, feel of a normal home and adoptability. The motivations of the project team are important in understanding what influences the decision-making process and what factors different parties consider to be important. These are discussed in the following paragraphs, which address an individual motivation or group of motivations.

7.4.1 Cost

The cost to build the houses was seen as one of the most important motivations, with many parties stating that affordability was key. The project manager stated that to realise the project he had to reign in the passion shown by many members of the team as "everything has to be balanced with affordability" and it was his job to make sure that happened. The contractor agreed that this was the "biggest driver", saying that "if it hasn't been viable we have had to change it and reach some compromise". The M&E consultant also concurred, stating that "one of the main key issues is probably affordability", but that this needed to be balanced "between the original aspiration and the actual affordability... so what will be delivered will be the right product". The project manager did admit that the houses would cost more to build, but qualified this by stating that this would be "considerably less so than say the reduced running costs". The second client was concerned that the contractors' main motivation was to "think about what savings can be made and what they can charge". The main client stated that there seemed to be a situation of "money versus vision", with finance being "a driving factor over and above the environmental issues" for some of the project team, which led to some compromises being made on design issues. The M&E consultant agreed with this, when he said that "always at the back of your mind, you're thinking, well who's going to pay for this, and that's what's obviously driving the compromises that have got between there and where we are now" (in relation to the environmental standard). The contractor was the only interviewee who mentioned profit, stating that "we're a business and we're in business to secure work. We're in business to make a profit and profit isn't a dirty word. We need to make a profit to give the owners of the company a return on their capital". He also said, in relation to the client, that "at the end of the day he wants to make a profit to invest back into the local community".

7.4.2 Environmental impact

As well as cost, environmental impact was seen as a very important motivation, with many parties referring to it. The second client stated that there needed to be a balance between affordability and "environmental benefits" and that the "social, economic and environmental aspects need to add up". The project architect thought that these issues were "on the news a lot more now" and as it "filters into public conscious" he seemed to think that people would be more concerned with how their houses perform and their expected energy consumption. The M&E consultant stated that "the whole thing is driven by the need to create a sustainable community" and that the client would be most concerned with the community aspects because "it is a part of a community that he's part of and I think that's quite important not just for him, but SEV's committee as well". The main client was motivated by delivering houses with high environmental standards, stating that "if we had compromised on the standards of the houses, we'd have been compromising on our own vision". He also said that he needed to "convince the rest of the design team to not only think to that standard, but to think beyond it and try to push even further". The M&E consultant agreed that this was an important motivation for the main client, stating that "the sustainable angle is all centred around achieving the EcoHomes rating that he's looking to achieve and going beyond". The contractor commented that the client's "vision concerning the environmental and sustainable issues... have been diluted a little, because commercially they were not viable". The M&E consultant and the third contractor stated that they were involved in the project partly because of the sustainability credentials of the development. The M&E consultant stated that he was involved because it was "something a bit more than a standard housing development, it is based around SEV's ethos of sustainability". The third contractor said that they were "very mindful of starting to get switched on, at that point, to the need for energy-efficient housing and sustainability".

7.4.3 Vision and interest

One of the client's main motivations was the vision for the project. He stated that "it always comes back to the touch stone of what we wanted, right from the beginning, so it's somewhere to live, work, learn and play". This was appreciated by the structural and infrastructure engineer, who said that "we took on board the thinking behind the project" and that he was "keen to work with that". The M&E consultant stated that sustainability had become an "interest and passion from the directors" and that it had "turned into almost a significant business".

7.4.4 Aesthetics

Aesthetics were only mentioned by others in relation to the architect's motivations. Several interviewees stated that the architect was very much concerned with the look of the houses, although he did not mention this himself. The project manager said that the architect is "trained, I suppose to think about aesthetics, about form, about functionality, about how space works". The second client was a little blunter, saying that "architects have one perception; they can paint pretty pictures". The main client identified particular design statements that the architect had wanted, but were redesigned without his input; this included the removal of render to the porches on some of the house types. The M&E consultant also mentioned some of these design statements that the architect wanted, but described them in a much more positive way. He said that the architect "wanted houses that would have a lot more architecturally shaped roofs, lots of overhands, lots of nice solar shading and all these sorts of things and lots of elevation treatments".

7.4.5 Quality and pride

Quality of the project was seen as a motivation by the client, who wanted a "high quality" scheme. The M&E consultant also stated that quality was a driver for the development, but the project manager went into the most detail. He stated that the "quality of materials we're looking for is a slightly higher level". He was also motivated by the architectural quality, stating that "architecturally we're looking for a higher design content". The project architect was the only member of the project team to talk about pride, with this apparently being one of his most important motivations. He stated that "I always just like to get things built, I like to be able to stand back when something's built and say, I did that, so I want something I can be proud of". He also thought that this was the same for the rest of the project team, especially the clients, who he said would "probably want something they can say to the community, 'We did this, it used to be a pit, look at it now'".

7.4.6 Demonstration

Several members of the project team felt that demonstrating that the case-study houses could be delivered with environmental and affordability considerations was very important. The project manager felt that this was especially important, and explained this as follows.

> Because if we want other people to follow, if we want the likes of your more regular national house builders to grasp the issue and to try and deliver in a sustainable and environmental way... we've got to demonstrate that it can be done and there is commercial reason to do it.

The main client and the third contractor were both keen that the project had to be commercially viable and should show the business case for the development. The contractor also thought that this was "an opportunity to have a demonstration project to demonstrate best practice in the delivery of housing". The structural and infrastructure engineer agreed with this when he noted that "it is good to set an example by this project as it is working".

7.4.7 Getting to site and time

Getting to site was one of the project manager's main motivations. He asked "until you've got it to site, who's going to pay a great deal of attention?" He also felt that he had to "bully the process, to make it happen". Time was stated as being a motivation of the project team as a whole, but this constraint was thought of as much less strict than for conventional developers. The architect stated that the process had "taken time" to get the houses "right and getting the development the client wanted to see". The M&E consultant agreed, stating that the extra time had been spent on "getting the standards, getting that balance between the original aspiration and the actual affordability right and so what will be delivered will be the right product".

7.4.8 Locality

The project manager and the architect stated that a motivation to be involved in the project was that it was local to them. For example, the project manager said that "it would not reflect well on our practice to have another architectural practice working on, effectively, your doorstep". The architect reinforced this by stating that this was "a fantastic opportunity, really, to develop an eco-housing scheme that was local, on our doorstep. We were on the site anyway and so it seems to make complete sense". The third contractor also noticed that the client wanted to work with "local suppliers and local contractors".

7.4.9 Best techniques and feel of a normal home

The project manager was concerned that the M&E consultants and the "structures guys... want to show off and use the best techniques available to try and deliver what they want to deliver and I completely understand that". The architect, however, was motivated by wanting the houses to feel like a normal house, saying that he wanted people to "come and look round and go, 'Erm, it's just like a normal house', but it's environmentally friendly".

7.4.10 Adoptability

The structural and infrastructure engineer was the only member to discuss the adoptability of the scheme, as he was concerned with the drainage solution and this needed to be combined with the highways authority's adoption criteria. Although no one else mentioned adoptability of the scheme, this was a crucial aspect of the success and completion of the development which seemed to be primarily the concern of the structural and infrastructure engineer. This issue may have been resolved more quickly if the other members of the project team were more engaged with the issue and better understood the different pressures on the adoptability of the infrastructure and drainage systems. However, the most significant issue causing delays in this area were external actors not giving permission and carrying out the work.

7.4.11 Conclusions

Cost, especially affordability, and environmental impact were the main motivations of the project team members. These were both seen as essential elements by most interviewees, but it was felt that some compromises on the environmental issues were made because of the cost restrictions involved. Several other motivations were discussed by interviewees, with many of them commenting on their 'external' perception of the motivations of others, rather than on their own 'internal' motivations. In most cases these motivations were agreed by the other parties, but in some circumstances there were discrepancies. These discrepancies can be identified in Table 7.5 which presents a matrix of who commented on specific items. Discrepancies can be seen where there are only 'internal' (represented by I), or 'external' (represented by E) motivations, such as aesthetics, which was the most prominent. The table also shows that the main contributors to the discussion of motivations were the architect, project manager, main client and the M&E consultant.

Theme (in bold) and elements	Project team member							
	Engineer	Main Contractor	3rd Contractor	Architect	Project Manager	Main Client	M&E	2nd Client
Cost	I					E	E	E
Affordability		I			I		IE	
Profit		IE						
Sustainability				I			E	I
Standards		E				I	E	
Involvement			I				I	
Other								
Vision	I					I		
Interest							I	
Aesthetics					E	E	E	E
Quality					I	I	I	
Pride				IE				
Demonstration	I		I		I	I		
Getting to site					I			
Time				E			E	
Locality			E	I	I			
Best techniques					E			
Feel like a normal house				I				
Adoptability	IE							

Table 7.5: Motivations referred to by project team members in their interview; internal (I) or external (E)

7.5 Environmental standards

This section reports what members of the project team said about the environmental standards at the case-study development. Four themes that relate to standards were identified from the data: EcoHomes; beyond EcoHomes; planning conditions; and the original concept for the development. The environmental standards were essential to the development of the case-study houses as they were one of the key principles of the project.

7.5.1 EcoHomes

EcoHomes was used as the environmental standard for the case-study houses. The main client stated that this was because "we needed a standard to be measured by" and that "the majority of the housing industry recognised that". The M&E consultant saw the most important aspect of the EcoHomes standard as the "quality and the detailing built in to achieve the quality". He stated that this was favoured over renewables and that the houses would not be "noticeably different" from conventional dwellings. The contractor was not convinced by the approach of meeting "the EcoHomes standard by thermal mass" and stated that it was "not exactly at the forefront of new construction methods" as he would have preferred to see non-conventional building techniques used, such as SIPs. The project manager saw the selection of the EcoHomes standard as a change in focus for the design process and that it stopped the project "trying to be all things to all men". He also stated that prior to the adoption of EcoHomes "we were designing a utopia on an unrealistic budget". The main client saw the EcoHomes excellent standard as a "stretched target" to achieve as "people were saying that they were struggling to do that". The project manager stated that the project team had to find the "cheapest most cost effective way of achieving EcoHomes excellent".

7.5.2 Beyond EcoHomes

To go beyond EcoHomes excellent was the aim of some members of the project team. The main client stated that he "wanted to give the options of solar thermal particularly" and that he had to "convince the rest of the design team to not only think to that standard, but to think beyond it and try to push even further". He added that it was "very easy for the professionals to slip into the comfort zone of EcoHomes excellent". The M&E consultant was "quite interested in the idea of taking EcoHomes as almost a minimum benchmark and then looking at what else you could bring in to create quality housing". The project manager stated that there was "still the opportunity to add technologies", but that "every penny spent over EcoHomes is effectively a pound off profit return". He seemed to favour giving prospective buyers the option to purchase renewable energy technologies as add-ons to the houses. The contractor was interested in being involved in "developing the add-on things that the clients are thinking of offering to purchasers in the form of extras". In the future phases of the development the main client thought that as more money became available, the houses would be "better performing the further in the site we go". The M&E consultant was keen for the incorporation of renewable energies in future phases, stating that there was "still scope to introduce a lot in the future". The main contractor was keen to "introduce SIPs further down the line".

7.5.3 Planning conditions

The planning conditions set for the site were renegotiated and the M&E consultant stated that "the EcoHomes rating wasn't really established until they'd gone through the first round of planning". He said that the planners were more concerned with whether the houses were energy-efficient and something exemplary for the area rather than specifically meeting the original planning conditions that stipulated a zero-heating standard. The planning condition for the zero-heating standard encouraged the planners to waive the normal requirements for the provision of affordable housing on site. The client noted that "the planners let us invest in all the houses to make them more affordable to live in. The planners then wanted some criteria to measure against", which was how the zero-heating standard was set as a planning condition.

7.5.4 Original concept

The original concept for the houses, as described by the M&E consultant, was a "highly sustainable development with really strong community links". He added that this included building to a zero-heating standard and that the houses as designed were "a long way from that". He also admitted that "at the back of your mind, you're thinking, well who's going to pay for this, and that's what's obviously driving the compromises that have got us between there and where we are now". The M&E consultant stated that "zero-heating standards would architecturally be something completely different from what they are at the moment". This indicated that the houses were not designed to zero-heating even though it was a planning condition when the designs were created. The project manager saw the need to "shift the emphasis in terms of what we were trying to achieve and what we had to design to" in reference to the zero-heating standard. He stated that "there are fundamental issues with zero-heating buildings" in terms of occupancy levels. He also argued that many members of the public believed that "you can't buy a house without a heating system". This would have meant that heating systems would have been included in houses built to be zero-heating, which to him seemed to be a waste of "huge amounts of money, that would really destroy the argument".

The main contractor admitted that the standard had to be "watered down because it wasn't commercially viable". The architect explained that the zero-heating concept for the houses was "entrenched in a lot of people's minds before we actually started working". This was because the very first sketches made for the housing development, years before the design process started, were entitled "zero-heating houses". The architect agreed with the contractor that "economic realities came into it a bit", with "lots of people either casting doubt on it or the financial viability of it". He also agreed with the project manager about the fact that to make the houses sellable they would need to have heating systems. He thought that it would be "nonsense" to install heating systems if they were not necessary. The architect also defended the design of the houses, saying that "if we had gone for a completely solar heated solution we would have had a very rigid site". This was not wanted by him or the clients and he compared this style of design with "1960s style estates" and stated that it was "too restrictive for the site".

The client explained that the number of houses planned on the case-study development had increased from 88 houses to 196. He stated that the original plan "wasn't commercial and wasn't realistic" as it had been imagined that very sustainable houses would be built with "large gardens to grow your own vegetables". He felt that this concept was "nice in theory or in an academic paper" but not in practice. The M&E consultant apparently felt a "certain amount of disappointment" about the compromises made between the original concept and the reality. He stated that this was partly down to members of the project team being "focused on getting in their own design initiatives into the project, not necessarily thinking about the wider needs of the development".

7.5.5 Conclusions

The environmental standard for the case-study houses was discussed by several members of the project team, with the main contractor, project manager, main client and the M&E consultant discussing it the most, as shown in Table 7.6. The comments concerning the EcoHomes standard were that there was a need for a recognised standard and that building to this standard would cost a little more. Going beyond the EcoHomes standard was important to some members of the project team, but they thought that this would happen on later development phases, especially with the introduction of renewable energy technologies. Planning conditions were renegotiated, with the initial document including a requirement for all houses to meet a zero-heating standard. This was renegotiated to EcoHomes excellent, but the provision of affordable housing that had not been required because zero-heating standards were to be achieved was still not a requirement. It was apparent that many compromises were made between these two standards, with these being attributed to economic factors.

Theme (in bold) and elements	Engineer	Main Contractor	3rd Contractor	Architect	Project Manager	Main Client	M&E	2nd Client
	Project team member							
EcoHomes		√			√	√	√	
Cost					√			
Beyond EcoHomes					√	√	√	
Future phases		√				√	√	
Options		√				√		
Planning conditions						√	√	
Affordable housing						√		
Original concept		√		√	√	√	√	

Table 7.6: Themes and elements of the environmental standard referred to by project team members

7.6 Barriers and ways to overcome them

In this section barriers noted by project team members that affected the development of low-energy housing are discussed. These barriers and ways to overcome them were identified from the interview data and were grouped under 13 categories: external agencies, cost, design changes, involvement, risk, time, government, construction industry, knowledge, demonstration projects, project team relations and value engineering. Barriers and ways to overcome them are very important for developers of future low-energy and zero-carbon housing developments to learn from.

7.6.1 External agencies and cost

Two major barriers to developing low-energy housing, identified by the interviewees, were external agencies and cost. The three external agencies referred to during the interviews were the County Council's highways and planning departments and the water company used on the site. The highways department were said, by the second client, to not "like trees" as their roots can cause problems. She went on to state that "finding something that would be accepted was achieved through continual dialogue". The architect thought that highways were the biggest barrier, as he "didn't want to do your standard house builders' layout", which is what he felt highways wanted. He found this "very frustrating because there is so much case study knowledge of passive road calming". The structural and infrastructure engineer also saw highways as a barrier because "you need to design it to comply with some fairly strict design standards" for the design to be adopted. SUDS (sustainable urban drainage system) in place on the development did not appear to meet these strict standards. The planning department was, according to the architect, "a barrier to developing quickly". The engineer agreed, stating that they "will be trying to control all of this". The engineer, who solely dealt with the water company, noted that they "grappled with the philosophy for this site" and that during the process he had dealt with four different engineers from the water company. Cost was discussed by the third contractor and the M&E consultant. The contractor explained that investing in innovative methods, such as SIP system, was necessary despite their current high costs so that economies of scale could develop. The M&E consultant stated that the additional cost of energy-efficient features and renewable energy technologies was the simplest barrier, as house buyers are often unwilling to pay more for these.

7.6.2 Design change, involvement, risk and time

Design change was seen as a barrier by the structural and infrastructure engineer as this had led to an increased number of dwellings on the site, which meant that the SUDS capacity was insufficient. The contractors noted that their involvement in the detailed design had not been early enough to incorporate a SIP system, which they felt was detrimental to the energy performance of the houses. The client was keen to limit risk involved in the site, and therefore went into contract with a relatively high (87%) cost certainty. This enabled him to demonstrate the low risk involved to the quantity surveyors, who had put a 30% risk premium on the figure he initially thought the houses could be built for. The main contractor mentioned his company's risk in being involved in the project, as "we've actually invested an awful lot of time and energy and money without any return". Time was also seen as a barrier by the main contractor, who stated that to begin with it was "not affordable and we found a compromise to make it affordable, so that has taken an awful long time and not everybody has got that time".

7.6.3 Government

The government was referred to as both a barrier and a way of overcoming barriers to delivering low-energy housing. The third contractor stated that low-energy housing seemed to be "very high on the government's agenda" but that "the funding doesn't seem to be there", going on to suggest that "more public sector support for developers" is needed. The main client thought that the government needed to give more guidance to housing developers on developing low-energy housing. The M&E consultant noted that both house owners and local authority housing associations get funding and guidance to build more sustainable homes, but private developers do not. He said that government needed to be "a bit stronger in their Building Regulations and their planning guidance in terms of saying to developers 'You can't develop more than this size of development without having, say a minimum of 30% renewables'". He said that as soon as this happened developers would "simply add five percent onto the cost of the houses, people will absorb that, and they'll recoup that through reduced running cost and things will go back to normal".

7.6.4 Construction industry

The construction industry was also seen as a barrier and a way of overcoming barriers to delivering low-energy housing. The architect stated that the "mindset of the contractor to actually go that little bit further" needed to be changed. He also said that contractors were reluctant to think differently from the traditional, conventional way of doing things, with money being the main problem. The main client stated that he had to work with several parties to make sure that things were done properly. These parties included: the bank and the quantity surveyor as they needed to be convinced that it could be commercially viable; the contractors to go beyond Building Regulations; the architects to "design something that can operate properly"; and the M&E consultants to specify something that would work in practice. The M&E consultants saw barriers with the "contractor being able to understand what they're building" and "how they've interpreted it and I think there are quality issues". The second client saw the construction industry as a potential solution, stating that "problems need to be taken to industry to solve the problems".

7.6.5 Knowledge, demonstration, project team relations and value engineering

Lack of knowledge was seen as a barrier, with the second client stating that the "conventional understanding of affordable housing" was a barrier as she thought that low-energy housing was "affordable to heat and therefore money isn't wasted heating the air". The structural and infrastructure engineer stated that knowledge about the site needed to be shared more and that the clients' perception of certain aspects, such as the drainage, was not quite correct. The main client explained that both the contractor and the project manager had, throughout the project, changed the way that they thought about certain things and would now consider the environmental impact of some decisions. The project manager saw the fact that "nobody has, thus far, demonstrated that it can be done in a commercial manner" as a barrier to developing low-energy housing. He felt that until this happened "you're never going to get businesses that are primarily there to return investments to their shareholders to consider it as an option". The main contractor discussed two ways of overcoming these barriers to ease the development of low-energy housing. The first was that the project team needed to work together. He said that "we've been working together to achieve that as opposed to someone sitting there and trying to protect their little bit. We wouldn't have got there". The second was the use of value engineering to reduce the build cost of the houses. He stated that "if we hadn't had changed the design and the specification we wouldn't have achieved the cost results that we have now been successful in achieving". He stated that the savings were between 20% and 30%.

7.6.5 Conclusions

Barriers to delivering low-energy housing and means of overcoming them were presented in this section. However, for several barriers, interviewees suggested no ways to overcome them. External agencies, such as highways, planning and the water company were seen as major barriers by some members of the project team. Cost was related to several of the barriers identified, with the cost increasing for low-energy housing due to risk premiums, a longer design process and lack of governmental support. It was argued by several parties that government should give stronger guidance and regulation as well as incentives and support for the development of low-energy housing. The construction industry itself was seen as a barrier and the view seemed to be that radical change was needed by all parties involved to improve knowledge about low-energy housing, to alter the mindset of these parties, and to get them to work together in a more integrated manner.

The matrix in Table 7.7 shows that several interviewees suggested barriers and how to overcome these to deliver low-energy housing, with the main contractor's input being particularly prominent. The table highlights that there were more barriers than ways to overcome barriers suggested by the interviewees.

Theme (in bold) and elements	Project team member							
	Engineer	Main Contractor	3rd Contractor	Architect	Project Manager	Main Client	M&E	2nd Client
Barriers								
External agencies	√		√	√				√
Cost			√				√	
Design changes	√							
Involvement		√	√					
Time		√						
Risk		√				√		
Government			√			√	√	
Industry				√		√	√	
Knowledge	√					√	√	√
Demonstration projects					√			
Ways to overcome barriers								
Project team relations		√						
Value engineering		√						
Government			√			√	√	
Industry								√
Knowledge							√	
Demonstration projects					√			

Table 7.7: Barriers and ways to overcome them referred to by project team members

7.7 Lessons

This section discusses lessons identified by members of the project team. These lessons were categorised into three groups: people-related lessons; quantifiable lessons; and future lessons. These are important for the delivery of future developments of low-energy and zero-carbon houses.

7.7.1 People-related

Themes emerging from the interviews that related to lessons concerning people included: knowledge, open mind, formation of the design team, and relationships. Increased knowledge was mentioned by four of the project team members. The project manager stated that "everybody's got a better knowledge now of low-energy design requirements". The second client and the M&E consultant both remarked on how much information they had collected from this project. The structural and infrastructure engineer also noted that the water company involved "had to grow with what we are trying to achieve on this site". The project manager thought that one has to "stay incredibly open minded in terms of achieving the end results", especially when meeting the EcoHomes excellent standard. The early formation of the design team was seen as a lesson learnt by the main client. He stated that "we brought in the builders and the estate agents early. If we hadn't have done that, the issue of saleability and buildability would not have raised their heads until a lot further down the journey". Relationships between project team members were only discussed by the main contractor, who felt that the good relationships established were key to the design process. He stated that it was only by working as a team that what was achieved on the project was possible. Although he seemed to feel at times that he was treated unfairly, especially when the project manager "wouldn't allow me to get my other colleagues involved". Nonetheless, he did say that "I think because of the relationship we've got and that has developed we've trusted each other a lot more and so I think it is extremely important that the relationship between people sitting around the table and the trust is developed".

7.7.2 Quantifiable lessons

Lessons learnt that can be quantified include those that address cost, detailed design, house types and time. The architect thought that one of the key lessons was to "understand how much it costs at an early stage", while the M&E consultant stated that it is "very difficult to make low-energy housing affordable". The project manager's lesson was that he wanted people to think about "the story we want to tell", which addressed the cost as well as the environmental impact of the houses. Detailed design of the houses was discussed by the structural and infrastructure engineer, who thought that the important lessons were to get the structural and architectural detailing correct. The architect noted that to understand the mix of houses needed was a lesson that should have been learnt earlier, as he said that he "almost tore up the design and started again" due to this. The main contractor, the main client and the second client all agreed that the time needed for the design process was longer than for conventional projects. The main contractor stated that "in the future, perhaps, people should allow sufficient time to do it" and the main client noted that "you need a lot longer to design and plan it properly".

7.7.3 Future lessons

Future lessons to be taken forward to forthcoming phases of the case-study development were mentioned by the main client. He stated that "everything we learn we incorporate and take it forward". The structural and infrastructure engineer discussed future lessons in some depth. He was interested to see how the SUDS on the case-study housing site would be "used and maintained" and thought that this would be "a learning curve for somebody". He also mentioned the fact that the local council would monitor the site as they would be keen to "observe how this will perform and they see that as an opportunity for the learning curve" to continue. He stated that this 'monitoring' by the local council would be on several levels and would look at parking, materials, geometry and accidents.

7.7.4 Conclusions

In summary, the interviewees reported several lessons learnt from the case-study housing project:

- An open mind is needed to achieve high environmental standards.
- Trusting relationships need to be developed between members of the project team.
- The project team should be formed early in the design process.
- Cost information is needed early in the design process.
- The detailed design of the houses is important to meet the environmental standards.
- An understanding of the housing market at the time of planning is needed to guide the house type designs.
- More time is needed to design and plan a project of this type than for conventional housing.

- Monitoring of the development into occupation is necessary to learn about ways in which occupant integration with the buildings may support or compromise the low-energy design strategy.

The matrix shown in Table 7.8 shows that many of the lessons were only discussed by one of the project team members. It also shows that, apart from the third contractor, all interviewees gave two or three lessons each.

Theme (in bold) and elements	Engineer	Main Contractor	3rd Contractor	Architect	Project Manager	Main Client	M&E	2nd Client
People related								
Knowledge	√				√		√	√
Open mind					√			
Project team formation						√		
Relationships		√						
Quantifiable								
Cost				√	√		√	
Detailed design	√							
House types				√				
Time		√				√		√
Future lessons	√					√		

Table 7.8: Lessons referred to by project team members

7.8 Chapter conclusions

This chapter has reported the perspectives of project team members interviewed at the case-study development, to get a better understanding of the design process from individuals' points of view. One of the key themes identified from the data is the lack of understanding about the costs of sustainability on the part of the contractor, especially at the beginning of the process. This was also true of the quantity surveyor, with both parties adding 20-30% onto the actual price of construction. The design process to develop low-energy houses was reported, by almost all members interviewed, to be longer than conventional developments. The project manager was the only member who stated that his knowledge about low-energy building had increased during the project. The main client agreed with this and suggested that the contractor had changed his way of thinking dramatically. No-one on the project team had experience of large-scale low-energy housing developments before this project, so this should have meant that everyone's knowledge would have been increased in some way, but this was only acknowledged by the project manager, who admitted to having no knowledge of the EcoHomes standard at the beginning of the project. Partnering and trust were seen as important during the development, especially to the contractor, who had the most to lose. This was helped by the history of working relationships between many of the parties involved in the project.

Cost, especially affordability, and environmental impact were presented as the strongest motivations across the project team. Some members did, however, feel that some compromises on the environmental features of the houses had been made because of their cost implications. This seemed to be the case with the environmental standard, which was changed from zero-heating, originally a planning constraint, to EcoHomes excellent. It was the aim of the main client and the M&E consultant to go beyond this standard on the first phase, but they were both much more confident that this would be achieved on future phases. Cost was sited as one of the biggest barriers for developing low-energy housing, with this being related to the longer process needed and the lack of financial support from government. External agencies and the construction industry were also both seen as large barriers, with radical change, especially in the construction industry, seen as necessary. Government was seen as both a barrier and a way to overcome several barriers, with calls for stronger regulations as well as incentives and support for private housing developers to deliver low-energy housing.

8. Discussion

In this chapter all findings from the three previous results chapters are considered together, along with findings from previous research. This chapter has six sections which explore different aspects of these findings as well as discussing additional data from members of other project teams. The six sections are: evaluation of the environmental standard achieved; compromises between the original concept and the environmental standard achieved; comparison of the project team's behaviour with their interview data; questionnaire for non-case study project team members; proposed design process model for low-energy housing; and lessons, barriers and ways forward. These sections are followed by a conclusion for the chapter.

8.1 Evaluation of the environmental standard achieved

In this section the initial assessment of the environmental standard, based on EcoHomes, to be achieved by the case-study houses is discussed. The provisional environmental standard achieved provides a measure of the houses' success, as monitoring of their actual performance was not possible due to time constraints. To assess the standard met, the most recent provisional EcoHomes summary (JDA, 2007) provided by the architects for the case-study houses was used. This was dated 2 July 2007. The case-study houses were assessed against the EcoHomes standard by members of the project team who were trained as EcoHomes assessors. The final EcoHomes assessment had not been submitted when the present thesis was completed (September 2007), so no actual rating had been given to the case-study houses, this was a limitation as the results of the assessment only look at the predicted score. In this initial assessment the case-study houses did not meet EcoHomes excellent, which was one of the driving principles behind the project.

Each of the seven topics covered by EcoHomes is discussed in this section and Figure 8.1 presents the weighting of each of the topics and shows that nearly 60% of all credits available could to be gained from the energy and materials topics.

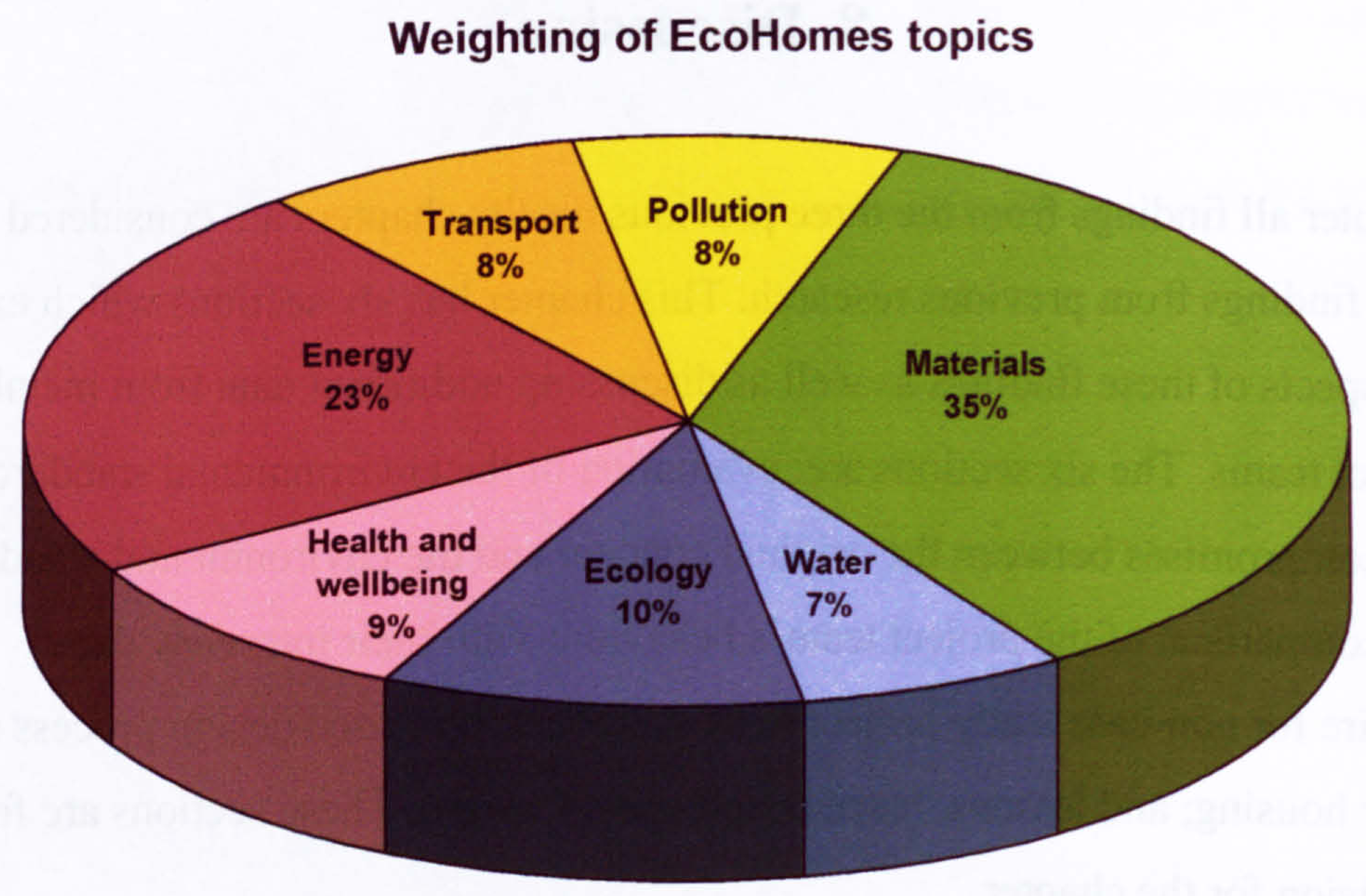


Figure 8.1: Weighting of EcoHomes topics

To achieve an EcoHomes rating, credits need to be scored for sub-topics under each of the seven topics. These are shown in Table 8.1, along with the credits gained, the percentage scored and whether each credit score would be easy to improve upon from the provisional assessment at the case-study development. To gain an EcoHomes excellent rating, 70% of credits were needed. This table is an extended version of Table 6.1, presented in the introduction to Chapter 6 (p.127).

Topic	Credit	Sub-topic	Credits available	Credits gained	% scored	Could score be easily improved?
Energy	Ene 1	CO2 emissions	10	6	60	No
	Ene 2	Building envelope performance	5	5	100	N/A
	Ene 3	Drying space	1	1	100	N/A
	Ene 4	Ecolabelled white goods	2	2	100	N/A
	Ene 5	External lighting	2	2	100	N/A
			Overall topic %		80	
Transport	Tra 1	Public transport	2	0	0	No; external agency
	Tra 2	Cycle storage	2	0	0	Yes; provide 50% cycle storage
	Tra 3	Local amenities	3	2	67	No; external agency
	Tra 4	Home office	1	1	100	N/A
			Overall topic %		38	
Pollution	Pol 1	Insulation ODP and GWP	1	1	100	N/A
	Pol 2	NOx emissions	3	3	100	N/A
	Pol 3	Reduction of surface runoff	2	2	100	N/A
	Pol 4	Zero emission energy source	1	0	0	Yes; provide 10% renewables
			Overall topic %		86	
Materials	Mat 1	Timber: Basic building elements	6	6	100	N/A
	Mat 2	Timber: Finishing elements	3	3	100	N/A
	Mat 3	Recycled materials	6	6	100	N/A
	Mat 4	Environmental impact of materials	16	5	31	No; materials have been specified
			Overall topic %		65	
Water	Wat 1	Internal water use	5	3	60	Yes; improve specification
	Wat 2	External water use	1	1	100	N/A
			Overall topic %		67	
Land use and ecology	Eco 1	Ecological value of site	1	1	100	N/A
	Eco 2	Ecological enhancement	1	1	100	N/A
	Eco 3	Protection of ecological features	1	1	100	N/A
	Eco 4	Change of ecological value of site	4	1	25	No; EcoHomes regulations
	Eco 5	Building footprint	2	0	0	No; densities
			Overall topic %		44	
Health and well being	Hea 1	Daylighting	3	3	100	N/A
	Hea 2	Sound insulation	4	3	75	Yes; increased acoustic insulation
	Hea 3	Private space	1	1	100	N/A
			Overall topic %		88	
		Totals	89	60	67	

Table 8.1: EcoHomes topics, credits, sub-topics and credits available for each

In the following paragraphs the credits provisionally gained at the case-study development for each of the EcoHomes topics are discussed.

Energy had five sub-topics and a total of 20 credits available. Ene 1 – expected CO_2 emissions for the houses was between 24-27 kg/m^2/yr, which would give six out of a possible ten credits. Ene 2 – a maximum of five credits would be scored for the building fabric as an improvement of 15% above building regulations on the houses' average U-value would be achieved. Ene 3 – providing drying space would score a maximum of one credit. Ene 4 – Ecolabelled goods would score a maximum of two credits, once confirmation was made by the client. Ene 5 – External lighting would also score the maximum of two, one of which was default for not having security lighting. Sixteen out of 20 credits (80%) were provisionally achieved for the energy topic. Any increase on this was stated in the EcoHomes summary for the case-study development as being difficult due to the current designs (JDA, 2007).

Transport had three sub-topics and a total of seven credits available. Tra 1 – public transport in the area was limited which means that no credits would be scored for this. Tra 2 – 50% of cycle storage was planned for the site, but this was not included in the design so no credits would be gained for this. Tra 3 – local amenities would achieve two out of three credits if the children's play area and public park planned have safe access, once confirmed by the client. Tra 4 – a home office space was designed in all house types, providing a maximum of one credit. Three out of seven credits (38%) were provisionally achieved for transport (JDA, 2007). The only increase available for this topic would be the cycle storage as the others were site-dependent.

Pollution had four sub-topics and a total of seven credits available. Pol 1 – all insulation has zero ozone depletion potential (ODP) and a global warming potential (GWP) of less than 5, which scores a maximum of one credit. Pol 2 – nitrogen oxide (NOx) emissions of equal to or less than 70 mg/kWh and boiler class 5 were specified for the boiler chosen by the M&E (mechanical and electrical) consultant. This would have gained a maximum of three credits.

Figures are not known, however, for the boiler chosen by the client and the contractor during the construction meetings. Pol 3 – reduction of surface runoff would gain a maximum of two credits, whereas Pol 4 – zero emission energy sources would achieve no credits (JDA, 2007). Six of the seven credits (86%) were provisionally achieved in this topic (assuring that full boiler credits were achieved), with the only improvement to be made by installing a zero-emissions energy source to provide ten percent of either the heating energy or non-heating energy for the houses, or five percent of total energy requirements.

Materials had four sub-topics and a total of 31 credits. Mat 1 and Mat 2 - source of timber for basic building and finishing elements. Maximum credits would be scored for each of these, six for Mat 1 and three for Mat 2, as 75% of timber had been sourced from temperate Forest Stewardship Certificated (FSC) forests. The certification and chain of custody needed to be confirmed by the contractor. Mat 3 – recycling facilities were designed inside and outside of all houses which would receive a maximum of six credits. Mat 4 – environmental impact of materials was rated against the *Green Guide for Specification* (Anderson et al., 2002). Each material was given a rating according to its environmental impact, although not all materials were covered in the guide. Five credits out of 16 would be scored on this sub-topic due to changes of materials in the internal leaf of external walls, internal block work walls and boundary protection. The score would otherwise have been 11 of out 16 (JDA, 2007). Twenty out of 31 credits (65%) were provisionally achieved for this topic, with the only improvements possible being the materials specification. However, to make Mat 4 more meaningful, the *Green Guide for Specification* (Anderson et al., 2002) needed to be updated to include a wider range of alternative materials.

Water had two sub-topics and a total of six credits available. Wat 1 – internal water consumption was estimated to be equal to or less than 40 m^3/bedspace/yr which would achieve three out of a possible five credits. Wat 2 – external water consumption would receive a maximum of one credit as a rainwater butt was to be installed at each house (JDA, 2007). Four out of six credits (67%) were provisionally achieved, with reducing internal water consumption further being the only way to increase the score.

Ecology had five sub-topics and a total of nine credits available. Eco 1 – the ecology value of the site would receive a maximum of one credit. Eco 2 – the ecological enhancement of the site would receive a maximum of one credit. Eco 3 – protection of ecological features receives a maximum of one credit. Eco 4 – change of ecological value of the site would receive one of four credits as the site was reclaimed longer ago than allowed by EcoHomes. Eco 5 – the building footprint of the site would receive no credits as only 40% was built to a ratio of better than 2.5:1 and 60% was needed for one credit and 80% for two (JDA, 2007). Four out of nine credits (44%) were provisionally achieved for this topic. This could only be improved upon if the majority of buildings on site were three storeys or if the definition of Eco 4 was changed to allow points for the reclamation of the site.

Health and wellbeing was the final EcoHomes topic and had three sub-topics with a total of eight credits available. Hea 1 – the maximum three credits for daylighting would be achieved. Hea 2 – sound insulation would provide three out of four possible credits as the intention was only to go 3dB better than Approved Document E. Evidence from an acoustic consultant would be required to see if this level was achieved. Hea 3 – all dwellings have 1.5 m^2/bedspace of private outdoor space, which would achieve a maximum of one credit (JDA, 2007). Seven out of eight credits (88%) were provisionally achieved for this topic, which could only be improved if the sound insulation was raised to 5dB better than Approved Document E.

In this section the EcoHomes environmental standard for the case-study houses has been outlined. The aim to achieve EcoHomes excellent for the first phase of the development would have required 70% of credits to be scored. The total score when the present thesis was submitted was 67.42%. This is shown, along with the potential score and the EcoHomes excellent score, in Figure 8.2.

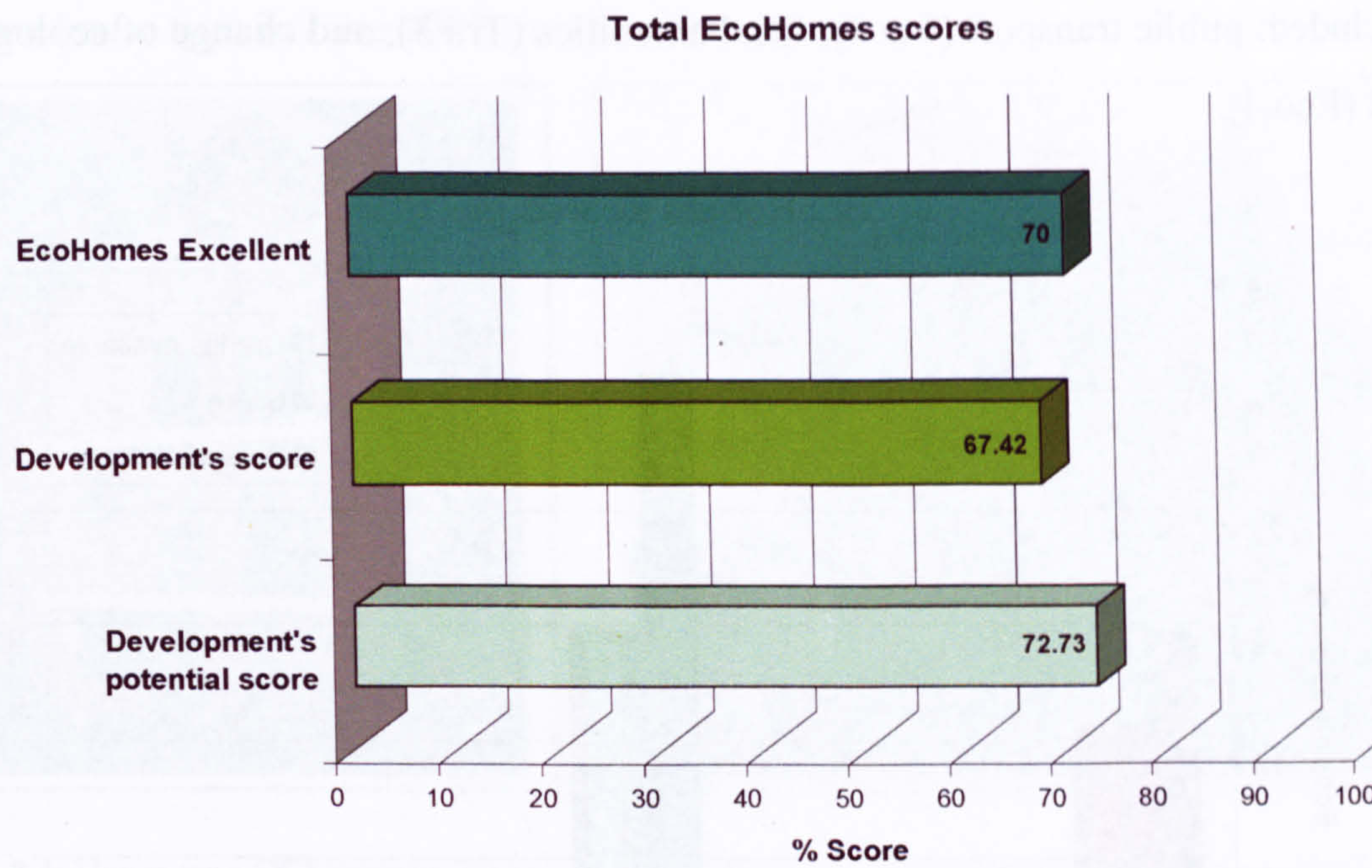


Figure 8.2: Total EcoHomes scores

The development's score could be improved in several ways. These are highlighted in Figure 8.3, where the potential score differs from the actual score for each topic. This shows that there are opportunities for improvement in the transport, pollution, water and health and wellbeing topics. To obtain an EcoHomes excellent score, three out of the five potential extra credits would need to be achieved. The credits that could be obtained are: cycle storage (Tra 1); zero-emission energy source (Pol 4); internal water consumption (Wat 1); and sound testing (Hea 2). These would all be fairly simple to achieve, but each has financial implications. Many credits that form the maximum score for each topic could not be achieved as the first phase of the houses was too far into construction when the assessment was being finalised. These were: carbon dioxide emissions (Ene 1); environmental impact of materials (Mat 4); and building footprint (Eco 5). The barriers to achieving these credits were more than just financial. They were related to the stage at which EcoHomes was considered in the design process and the specification and procurement of materials that had a lower environmental impact. Many materials were changed from those originally specified to meet the EcoHomes standard. The other credits not achieved were site-specific and could not be obtained due to the constraints of the site, these included: public transport (Tra 1); local amenities (Tra 3); and change of ecological footprint (Eco 4).

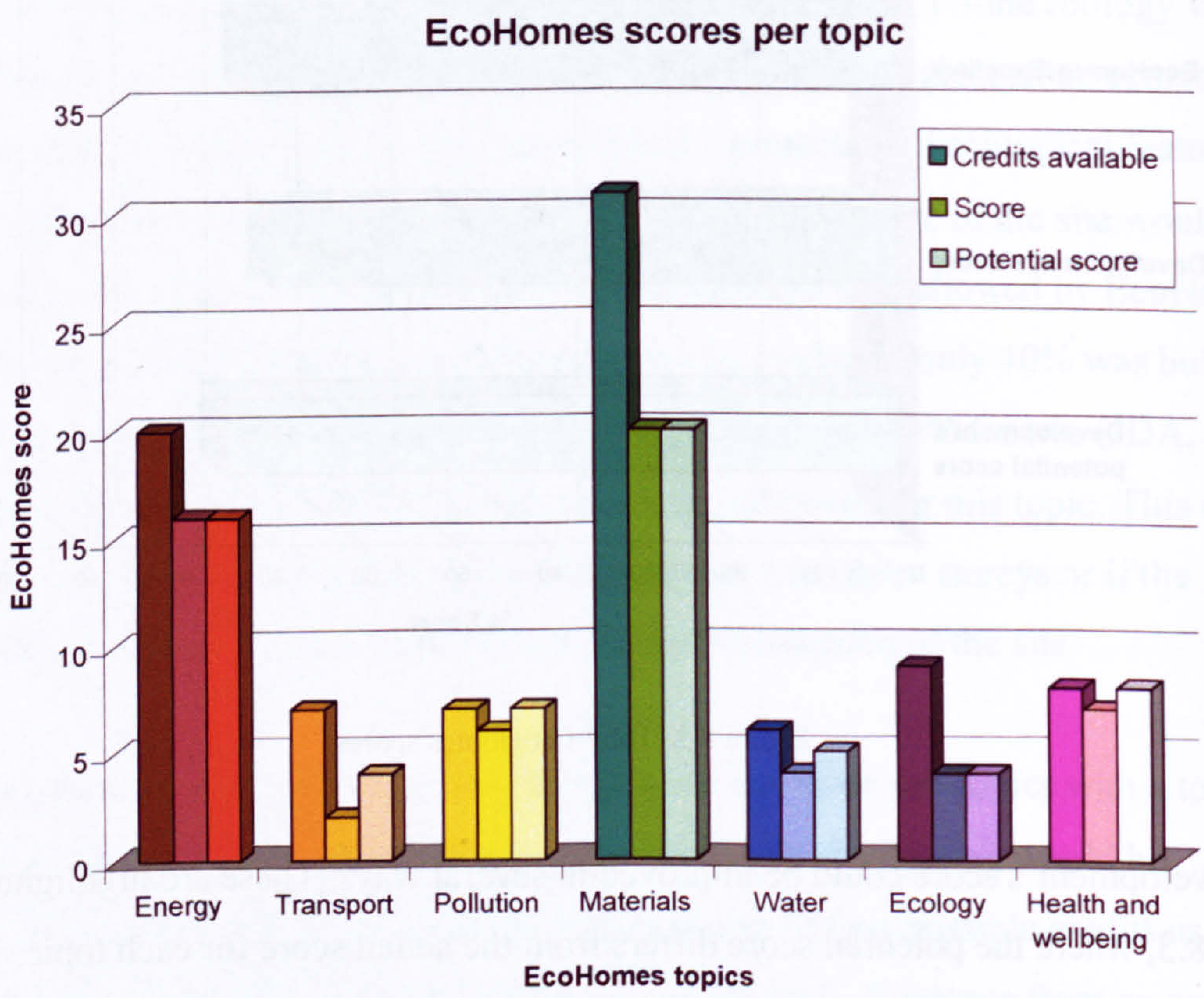


Figure 8.3: EcoHomes scores per topic

The Code for Sustainable Homes (outlined in Chapter 1, section 1.2, p.11) replaced the EcoHomes standard but has very similar categories. The information available on the EcoHomes assessment for the case-study development suggests that the first phase of the development would achieve a level 3 for the Code for Sustainable Homes. This level is equivalent to the proposed revision of the Building Regulation's Part L for 2010 (DCLG, 2006b) and is therefore the next nationwide step in the development of low-energy houses.

The present thesis was submitted in September 2007, at which point the houses at the case-study development had not been completed. Figure 8.4 shows a computer generated image

(CGI) of what one of the house types would look like and Figure 8.5 shows the progress of the same house type in June 2007.

Figure 8.4: House type CGI (source: JDA)   Figure 8.5: Construction, June 2007 (source: JDA)

8.2 Compromises between the original concept and environmental standard achieved

This section looks at how the environmental standard for the case-study houses changed over time. Reasons for these changes are identified and a discussion is presented of how to avoid weakening the environmental standard for future low-energy and zero-carbon developments.

The environmental standard to be achieved by the case-study development is shown in Figure 8.6 against time. This graph shows the changing environmental standard from the 2001 *Planning Brief* (NSDC and SEV, 2001) for the development, until the construction of the houses. The graph shows that there were four environmental standards that were aimed for during the period it was under discussion.

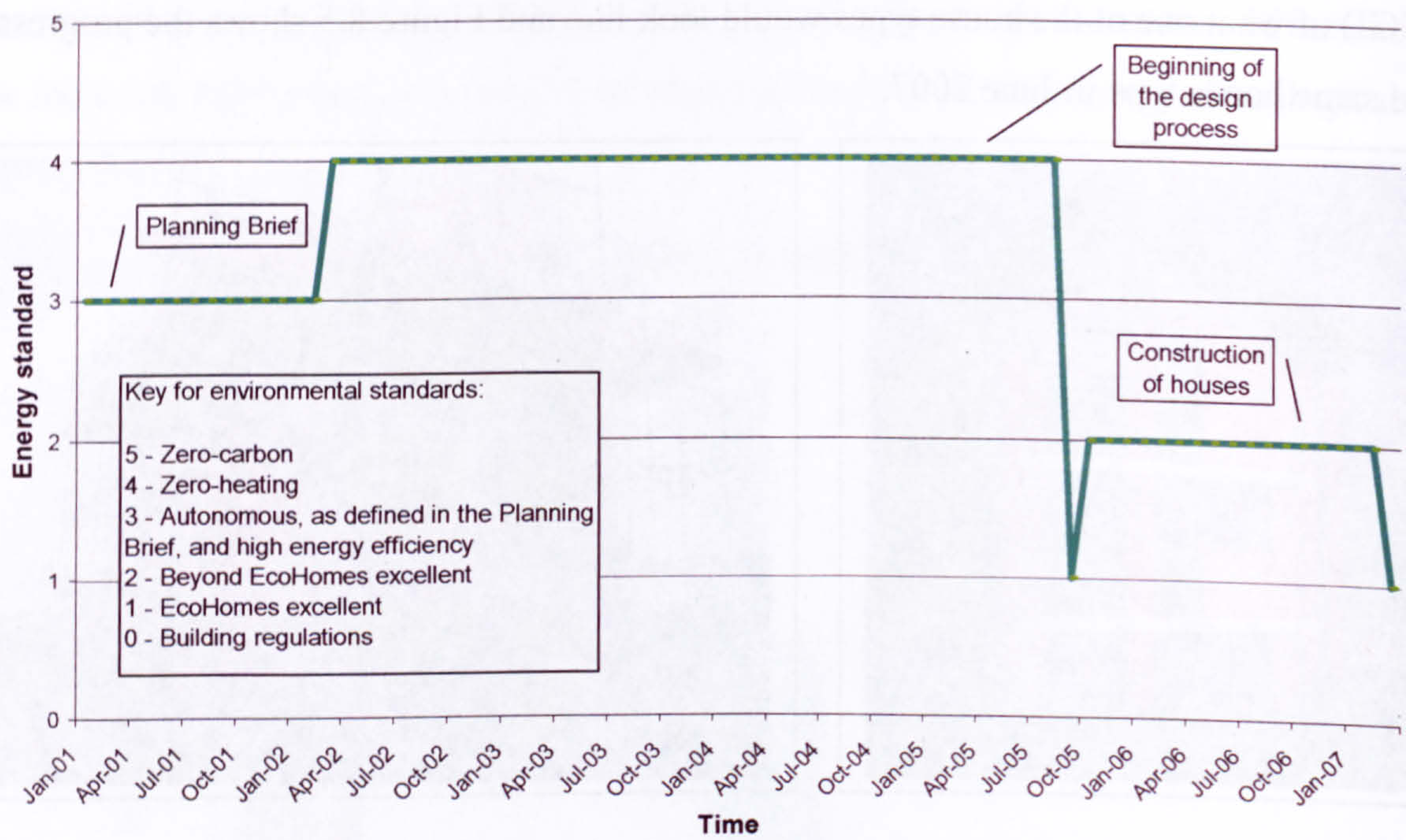


Figure 8.6: Environmental standard to be achieved by the case-study development

Figure 8.6 represents an overview of the level of the environmental standard to be achieved, rather than the view of any one member of the project team, as they each had different opinions on the matter. The first standard was outlined in the *Planning Brief* (Ibid, p.12-13), which stated that:

> All housing development on Sherwood Energy Village will meet high energy efficient standards. A total of 80 dwellings in a medium density setting could be accommodated on an area of approximately 2.83 hectares designated for housing on the northern side of the site, including:
>
> - 12 Autonomous houses – self-sufficient in terms of energy, water and sewage needs.
> - 3 Eco-demonstrator houses – showcasing the latest housing technologies for sustainable and environmentally sound building techniques. These will be open to visitors as a showcase for these technologies.

- 24 Self-Build Housing – with design and technical standards approved by Sherwood Energy Village. It is unlikely that single speculative self-build will be included.
- Other housing will be expected to be built to high energy efficient standards and to meet identified housing needs in terms of type of tenure, accessibility, size, design and cost. Housing types may include family houses, bungalows or flats.

This environmental standard was then raised to zero-heating between the *Planning Brief* being published in 2001 and the beginning of the design process in 2005. The job architect stated that the zero-heating standard was "entrenched in a lot of people's minds before we actually started working" because this was referred to in the very first sketches for the houses. The *Design Statement* (JDA, undated) and *Project Execution Plan* (SEV, 2005) for the housing development both outlined the zero-heating standard as well as mentioning the EcoHomes excellent standard. The zero-heating standard was part of the planning conditions for the site. The EcoHomes excellent standard was chosen as the minimum starting point and it was decided that this would be worked to in design team meeting 11 (September 2005). A standard beyond this was aimed for by some members of the project team, including the clients, M&E consultants and the architect, from the meeting after this until construction. Other members, including the project manager and the contractor, however, were working to EcoHomes excellent.

The reasons for the change in the environmental standard from zero-heating to EcoHomes excellent can be associated with three main areas. Firstly and most prominently, cost was the biggest driver for the compromises made. One of the key aims of this development was that the low-energy houses should be delivered in a commercially viable manner, which was not seen as being possible by the project team if the zero-heating standard was to be achieved. The contractor provided high quotes for costs for both this and the EcoHomes standard discussed, which was partly due to his lack of understanding about some of the costs and the risk premium added because of this. Once EcoHomes excellent was agreed to by the rest of the design team the cheapest, most cost effective way was sought to achieve this standard by the project manager, as the zero-heating standard was seen as unrealistic and too ambitious on the budget available. A standard between the two was not considered as the project manager felt that "every penny spent over EcoHomes is effectively a pound off profit return". Secondly, the zero-heating standard was viewed with some scepticism in terms of whether it would actually work. It was felt by the majority of the design team that the houses would not be sellable without a heating system. This would mean that any money that could potentially be saved by building to the zero-heating standard could not be spent on construction as a heating system would still need to be purchased. Finally, several members of the design team were keen to go beyond the standard achieved by supplying renewable energy technologies, but because these were seen as fairly easy to add on afterwards they were favoured as 'purchasers' extras' rather than as standard on the houses.

The compromises detailed above might be avoided on future developments if the following steps, abstracted from observations of the case-study development, are taken:

- A realistic standard, with a matching budget, is set.
- The environmental standard is embedded within the principles of a project and all project members agree on the standard to be achieved.
- The standard chosen is well communicated to all parties involved and they 'buy into' it.
- Training is provided for those parties who need to improve their understanding of particular environmental features.
- Specific prices for environmental features are sought to avoid additional costs being added, due to lack of knowledge.
- An environmental standard is shown to work based on previous evidence, such as the case-study development.
- The most is made of the attributes of the site, such as orientation for solar gain.
- More money is made available to meet environmental standards, which could be sourced from:
    - Government, in the form of grants, incentives or subsidies.

- Developers, by reducing their profit margins.
- House buyers, to cover additional cost of some features.

8.3 Comparison of project team members' behaviour with interview data

In this section the actions of project team members during the design team meetings are discussed with relation to their interview data. Six areas are focused on: cost, environmental impact, locality, interest, best techniques and 'feel of a normal home'. These were all expressed as motivations for making design decisions during the interviews. Eight other motivations were also identified, but these were not explicitly expressed during decision making in the design team meetings.

Cost and environmental impact were by far the most important motivations exhibited by the project team members when making design decisions. All project team members interviewed, apart from the structural and infrastructure engineer stated that they were motivated by both cost and environmental impact when making design decisions.

The architect and the M&E consultant both mentioned cost when interviewed, but were not seen to act on this during the design team meetings, which could have been because other members of the project team were over compensating for this aspect. The architect stated, when interviewed, that "one of the key lessons is to perhaps understand how much it costs at an early stage". The M&E consultant, when interviewed, stated that "one of the main key issues is probably affordability", but added that this needed to be balanced with delivering the right product. He also stated that he always wondered who was going to pay for all the elements that were in the original concept, such as the zero-heating standard and renewable energy technologies.

The main client was concerned about the commercial viability of the project and realised that some changes to the original concept needed to be made because of this. He wanted to show the business case for the development so that other house builders would see that low-energy houses could be delivered commercially. He noted, when interviewed, a concern for the fact that some members of the project team saw costs as more important than environmental issues. During the design team meetings he stated that he wanted to meet the EcoHomes excellent standard in a commercially viable way. He also made compromises with the selection of materials due to cost, such as not using timber for the rainwater goods. He was dedicated to using non-PVC wiring in the houses and was not put off by the contractor's overestimation of the cost for this. He also made the decision that no renewable energy technologies would be provided in the houses, due to cost implications, but did consent to spending more money on making the houses 'solar ready' so that if people were willing to pay for solar thermal panels they would be very easy to install.

The project manager seemed to be motivated by cost more than any of the other project team members. Affordability and the cost of the houses were both discussed by the project manager when he was interviewed. He admitted that the cost to build the houses would be slightly more than a conventional house but that the running costs would be considerably less, saving money in the long term. Affordability was the driver for most of the decisions the project manager made to reduce the cost of the houses. He stated, when interviewed, that he was responsible for controlling the passion of other design team members, as affordability was key. Cost was discussed a great deal by the project manager when insulation levels for the houses were decided upon in the design team meetings. He was keen to make sure that any extra money spent on insulation was going to be balanced by an increase in performance. A cost matrix was created for assessing this. He was also keen to keep the cavity walls of the houses the same as conventional houses so that the contractor was familiar with the construction techniques. Building to certain cost parameters was identified as a motivation by the project manager and this was exhibited during the design team meetings. The project manager insisted that the contractor go back to the cost estimates provided as he believed that they were unacceptable and that additional cost had been factored in to cover the risk of unfamiliar products and materials. The project manager, whilst being interviewed, stated that he embraced the EcoHomes excellent standard as it stopped the project "trying to be all things to all men". He also stated that he was keen to meet the standard in the most cost effective way possible and stated that "every penny spent over EcoHomes excellent is effectively a pound off profit return". During the design team meetings he stated that he was keen to make sure the M&E consultants weren't let loose with the extra money assigned to achieve EcoHomes excellent as he was worried about the cost escalating.

The contractor stated in his interview that his role was to put together preliminary costs, make recommendations on costs and go through the process of value engineering, all of which are based around costs. The contractor stated that he was motivated by making a profit so that he could give his company a return on its capital. He also stated during the interview that he was motivated by the project being commercially viable and that this was the reason that the original concept for the development was not achieved. During the design team meetings he showed that cost was one of his motivations when providing cost estimates for materials. He wanted to substitute the insulation chosen for a less expensive option as well as not wanting to specify non-PVC wiring as he thought that it would be much more expensive than it actually was.

The contractor, when interviewed, also seemed to be motivated by the environmental impact of the houses and stated that he was keen to help to develop the incorporation of renewable energy systems. He referred to wanting to be involved in developing the four earth sheltered houses for the site. He stated concern for the energy performance of the houses as SIPs (structurally insulated panels) were not to be used, because the contractor's involvement had not been early enough in the process. These two elements seemed to have commercial advantages associated with them, however, and so may not actually have been motivated by environmental issues. During the design team meetings he asked that several selections be justified, such as the decision to use wet plaster rather than dry lining. The contractor also assumed that the fires to be fitted in one particular house type were to be gas effect. This had never been discussed, however, and they were actually to be wood-burning stoves as gas fires are inefficient.

The environmental impact of the houses was a motivation for the project manager, but when interviewed he stated that he saw this as less important than delivering the houses affordably so that other developers would see there was a commercial reason for building in this way. He also stated that he wanted to build to EcoHomes excellent in the most cost effective way and that any decisions to go beyond this were to be decided by the client. During the design team meetings the project manager helped to ensure that EcoHomes excellent was achieved by reminding other members of particular credits that should be met, such as material selection. He also stated when he thought full credits should be achieved, such as for insulation. The project manager was the driving force to get the planning conditions changed to EcoHomes excellent from zero-heating, as he saw this as an unrealistic and over-ambitious target. He often steered decisions to the most cost effective choice to meet the criteria set out in EcoHomes excellent, such as for the rainwater goods. He stated that other conventional housing developers would take this approach to much greater extremes and would not give any consideration to the actual energy performance of the houses, only to meeting the EcoHomes excellent standard. He was committed to going beyond EcoHomes excellent where this was affordable, such as adding extra insulation.

The main client was highly motivated by the aim to create a sustainable development for the local community and, when interviewed, stated that "if we had compromised on the standards of the houses, we'd have been compromising on our own vision". He also felt that it was his job to get the other members of the design team to go beyond the EcoHomes excellent standard. In his interview he spoke about future phases of the development and said that these would be increasingly better performing as the site developed. He stated that he wanted to source local materials, but that sustainability was the priority. In the design team meetings this meant that he encouraged bricks to be sourced from further away because they had lower embodied energy due to one of the processes used to produce them. During the design team meetings he also suggested using recycled materials on several occasions as well as LEDs (light emitting diodes) to reduce energy use from lighting. When interviewed, the main client stated that he was not entirely happy with the decision to have gas on the site, rather than using renewables, but during the design team meetings it was decided that no renewable energy systems were to be installed due to cost implications. He strove to make sure that the houses were 'solar ready', investing more in this by specifying a boiler and heating system that were compatible and indicating that all connections for the panels were installed inside the houses.

The second client was motivated by reducing the environmental impact of the houses and during her interview stated that affordability needed to be balanced with environmental benefits. She was keen that social, economic and environmental aspects were all addressed. During the design team meetings she suggested several alternative materials to the ones specified. These were usually very low-impact, but very expensive, such as insulation made from wool. These were seen as being commercially unviable by the rest of the design team. She was also very keen for the timber policy, developed for the houses, to be communicated to everyone involved in the design process, but this did not come to fruition as she did not attend the meetings where it was to scheduled to be discussed.

The architect was motivated by reducing the environmental impact of the houses and supported this by stating in his interview that he always tried to incorporate environmental strategies into buildings. During the design team meetings the architect had to justify a lot of decisions that had been made, such as why he had designed the windows to be set back into the walls more than usual and why the eaves were larger than usual. This was to protect the timber windows from the weather, prolonging their usable life. He also referred to guidance about which materials should be specified according to what their impact was.

The M&E consultant was very much motivated by reducing the environmental impact of the houses and stated, when interviewed, that part of his job was to help set the performance specification for the houses as well as being an energy advisor. He stated that the most important part of the EcoHomes standard was the quality and detailing. He was very keen for the houses to include the boiler that he had specified and thought this was one of the most important elements. In his interview he also stated that in future phases of the development he was keen that renewable energy was incorporated. He seemed a little disappointed that no renewable energy technologies were incorporated in the current phase due to affordability. He also stated that he thought that developments should have to supply a minimum of 30% renewables, which is much more stringent that the ten percent under the Merton Rule (described in Chapter 1). During the design team meetings the M&E consultant expressed very positive attitudes to renewable energy technologies, but he was absent from the meeting when the decision was made to not include any. In the design team meetings he also encouraged the incorporation of a full rainwater recycling system. He also stated that one of the reasons he wanted to get involved in the development because of the sustainability credentials of the development and that it was an interest and a passion of his company.

Sourcing local materials and labour was discussed by the third contractor when he was interviewed with the main contractor. He did, however, mention this in relation to what the client wanted rather than what he personally wanted. The project manager and the architect, whilst being interviewed, both stated that they had wanted to be involved in the project as it was very local to them (they are both based on the site of the case-study development). Although they did not mention that materials and labour should be sourced locally in their interviews, they did remind the project team of this in design team meeting 12 in relation to brick and block.

Best techniques were referred to by the contractor in his interview when he stated that achieving the EcoHomes standard by thermal mass was "not exactly at the forefront of new construction methods". He also stated in his interview that he was very keen to incorporate SIPs into the house designs, but was involved in the design process too late for this to be possible. During the design team meetings the contractor discussed the possibility of using SIPs on several occasions, but when he discussed the house designs with the SIPs designers, they stated that they were incompatible.

Most of the project team members exhibited a variety of motivations that were consistent with their actions in design team meetings. The main client's were the most balanced, with both cost and reduction of environmental impact being significant. The architect, M&E consultant and the second client were seemingly motivated much more by reducing environmental impact, but they all said that they realised that the project needed to consider commercial viability. However, they did not always demonstrate this in the design team meetings, which may be due to other members of the project team overcompensating for this aspect. The project manager and the contractor were much more concerned with the economic realities of the project. This was, however, part of their job descriptions. There were a few discrepancies between the stated motivations in the interviews and behaviour in the design team meetings, including: the M&E consultant, architect and second client mentioning the importance of cost when interviewed, but not acting on this in the design team meetings; the contractor stating, when interviewed, that he was concerned by the environmental impact of the houses, but not acting on this is the design team meetings; the second client stating great concern for the environmental impact of the houses when interviewed, but not making sure that the timber policy was incorporated in the procurement process.

8.4 Questionnaire for project team members

In this section a questionnaire sent to members of project teams, not involved in the case-study development, to add additional data to this discussion chapter is described. The questionnaire was designed to collect information from members of project teams to assist in answering the research questions and to assess whether the research being conducted was relevant and useful to members of project teams. The questionnaire, shown in Appendix G, p.279, included a short introduction about the research and a reassurance that the respondents would not be identified, followed by six questions:

1. What is your profession?
2. Do you use the RIBA *Plan of Work* to guide projects you work on?
    a. If yes, do you think it helps you to incorporate sustainability into these projects?

3. Do you use any other guidance to assist with the incorporation of sustainability into projects?
    a. If yes, what do you use?
4. Would you find a model of the design process that highlighted relevant considerations and gave guidance about the incorporation of sustainability useful when developing sustainable buildings, especially housing?
    a. If yes, what form would you like this in?
5. How do you think the design process for sustainable housing (or other sustainable buildings if you don't have experience of houses) differs from that of conventional houses?
6. What do you see as the barriers and solutions to developing sustainable housing (or other sustainable buildings if you don't have experience of houses)?

The questionnaire was sent via e-mail to the following organisations on 27 June 2007, with a requested return date of 13 July 2007:

- Architects and quantity surveyors met at an *Architecture Week* event: Energy in Buildings at Leicester's Creative Business Depot on 19 June 2007.
- Architectural practices that belonged to the Leicestershire and Rutland Society of Architects.
- Organisations listed as low-carbon consultants from the Chartered Institution of Building Services Engineers (CIBSE) in the Midlands.
- Members of the Association of Project Managers in the East Midlands.

The organisations were chosen to cover a wide range of professionals involved in the design process and the questionnaire was sent to local organisations as it was thought these would be more willing to respond. Each recipient was asked to give the questionnaire to any member of their organisation involved in project teams who might be interested in completing it. The respondents were then asked to e-mail their answers to the author of the present thesis. The questionnaire was sent to 38 organisations and individuals and 11 replies were received, giving a response rate of 29%. Responses were received from:

- Six architects
- Three quantity surveyors, two of whom were also project managers
- One building services engineer
- One environmental consultant

The following paragraphs give an overview of the responses to the questions outlined above. The RIBA *Plan of Work* was used by six (55%) of the respondents, including the majority of the architects as well as two of the quantity surveyors. Of these six, only two stated that the *Plan of Work* helped them to incorporate sustainability into their projects. Nine (82%) of the respondents stated that they used other guidance to assist in the incorporation of sustainability into projects. Nine different examples of guidance were listed by the respondents, with the most cited source being BRE (Building Research Establishment) publications, which six respondents said they used. Two used the BRE's Code for Sustainable Homes. Experts in the field were the next most consulted source, with three respondents using other professionals to obtain advice. CIBSE publications and books on the subject were used by two of the respondents. Publications from the Association for Environmentally Conscious Building, Good Practice Guidance, the Carbon Trust and articles in architectural press were each stated as being used for guidance by one respondent. This data suggested that the RIBA *Plan of Work* was not enabling those who participate in the design process to easily incorporate sustainability into the projects they work on. The guidance used was varied, but the BRE was consistently mentioned as a source of information.

All of the respondents stated that they would find a model of the design process that highlighted relevant considerations and gave guidance about the incorporation of sustainability useful in the development of sustainable buildings, especially houses. Seven of the respondents (64%) stated that they would find a flowchart the most useful form for this model. Four respondents thought that a checklist would be useful, with two of these wanting both a checklist and a flowchart. One respondent, an architect, stated that the checklists should be "supplemented by questions to suggest which lists are relevant and information to guide selection". Another respondent, the environmental consultant, stated that they would find "a cheaper more accessible version of EcoHomes" useful. The responses strongly suggested that there is a need for a model of the design process that helps to incorporate sustainability and that most of the respondents would like this represented as a flowchart, with several also wanting a checklist. In the next section a model of the design process for low-energy housing is presented and in Appendix H, p.281, the associated lessons learnt are presented in the form of a checklist.

The respondents reported four ways in which the design process for low-energy housing was different from that of conventional housing. The main one, mentioned by five of the respondents, was that all parties involved in the design process needed to be committed and involved in the process from the beginning and that they needed to work together more closely. Three respondents stated that the focus for conventional projects was very different. One of the architects stated that conventional developers viewed the design process differently because "sustainability offers long term savings and many developers base decisions on the short term", while another thought that the "focus is on reduction of CO_2 emissions, conservation of energy, waste recycling etc. rather than on costs, programme, density etc.". Two respondents stated that heating and services and building methods needed to be more integrated in the design process for sustainable housing. Finally one respondent stated that as the design process for sustainable housing is more thorough it takes longer in the early stages. These comments are consistent with the findings from the present research and have been incorporated into the lessons learnt presented in Appendix H.

Cost was seen as the biggest barrier to developing low-energy housing with nine respondents mentioning it. These barriers related to:

- "The capital cost of sustainable energy plant and equipment" referred to by building services engineer.
- The "perceptions by key stakeholders that sustainable approaches to development automatically increase construction costs, when in most cases this is a myth" referred to by an architect.
- Affordability for house buyers, especially first-time buyers.

Three of the respondents felt that the government could contribute to solving cost problems by making more grants and subsidies available and by increasing Building Regulation standards. The project team was seen to be responsible for helping to deliver low-energy housing, with respondents stating that they needed to be coordinated, work together and that all parties needed to 'buy into' the concept. Several other barriers were noted by individual respondents, these included: unfamiliar design and technology; builders being slow to change the way they work; expensive assessment tools; high density requirements; adequate ventilation needed in airtight houses; house builders are very conservative and worry that the houses may not sell; and research and development problems. This suggests that the respondents felt that there were more barriers to developing low-energy houses than there were ways of overcoming these.

In this section a small questionnaire survey of individuals involved in the design process has shown that the RIBA *Plan of Work* is probably not adequate to enable the incorporation of sustainability into the design process for low-energy housing and that a flowchart and checklist would be useful. The results have also reinforced some of the findings from the present research. The results from questions five and six have been incorporated into the lessons learnt presented in Appendix H.

8.5 Proposed design process model for low-energy housing

In Chapter 5, section 5.8, p.122, a very basic model of the design process for low-energy housing is included in Figure 5.16. In this section, the model is further developed based on three sources of information: reflections on the observed case-study design process; data from the questionnaire for project team members; and findings from previous research. It is stressed that the proposed model is offered as a tentative tool that could assist developers of low-energy housing, as it has not been empirically tested. It does, however, include elements derived from the empirical work reported in the present thesis. One such element is a time dimension, with feedback and influence loops added to give a more realistic illustration of the design process. Appendix H, p.281, presents lessons learnt that correspond to the proposed model, these could be used to form guidance that could help enable those involved in developing low-energy housing to incorporate sustainability. Appendix H, p.281, identifies the sources that influenced the lessons learnt that could correspond to the proposed model.

The proposed design process model for the delivery of low-energy housing is shown in Figure 8.7. The model shows 15 stages of the design process along the left hand side, with those phases that are of particular importance to the incorporation of an environmental standard highlighted. Each stage of the design process is represented by a bar plotted against time along the x-axis of the diagram. The bars indicate the relative time period for each phase. This temporal aspect of the proposed model was influenced by data collected from the case-study development, but it is acknowledged as being approximate and subject to change, as each design process is unique. The stages are followed in sequence through the process. Some stages overlap, such as 'set/agree principles/standards' and 'design brief'. It is suggested that some other stages can only occur after one another, such as 'tendering' and 'procurement', and 'contracts' and 'construction'.

The addition of the stages 'formation of team', 'set/agree principles/standards', 'specification' and 'contracts' was based on empirical data collected during the present research. Reflections on the observed design process indicated that these were important in the achievement of low-energy housing. Observations that informed the inclusion of these additional stages are as follows. 'Formation of team' was deemed important because: all parties must be committed from the beginning of the design process; good working relationships and communication must be established between project team members; and partnering, transparency and trust must be embraced by all parties in the project team at the beginning of the design process. 'Set/agree principles/standards' was included because: all parties must agree to and be committed to standards and principles set; performance targets must be set for a range of parameters; and environmental standards must be appropriate and realistic for the development. 'Specification' was included because: detailed specifications must be developed and communicated to all members of the project team; specification for the heating and hot water system should be set as early as possible and should be efficient as possible, as this makes a large contribution to energy use in houses; detailed information on system operation, efficiency and cost is necessary to make decisions on materials and products; and specifications should be discussed with members of the project team with expertise in the particular area under consideration. 'Contacts' was added because: the contract is important to ensure that agreed environmental standards are adhered to in the construction of the houses; all parties should be involved in the creation of the contract documents; and the contactor may need to be negotiated with in relation to overheads, profit margins and incentives.

The proposed design process model has three feedback loops, shown by dashed lines in Figure 8.7. The first of these links 'final design' to 'outline design', representing the cyclical process that can occur during the design phases to create the optimum design. The second loop links 'final design' to 'appraisal', representing the process of recording decisions in a current project so that they can be fed into future projects. The third feedback loop links 'evaluation and monitoring' to 'appraisal'. This represents the process of feeding all building performance information from one project into future developments, to illustrate the effect of design decisions on the environmental performance of completed buildings. The proposed feedback loops are intended to represent ways in which the design process could be structured so as to encourage the incorporation of environmental features. These feedback loops are based on reflections on the design process at the case-study development and, as with all other elements of the proposed model, they require testing and possible refinement in future low-energy design processes.

As well as feedback loops, there are links from 'set/agree principles/standards' to six later phases of the design process. These are intended to illustrate the need for principles and standards to be revisited in these six phases: outline design; detailed design; final design; tendering; contracts; and procurement. The inclusion of these links in the proposed model is based on analysis of the case-study data presented in section 5.1, p.88, which showed that setting and revisiting principles was a very important aspect of the observed design process.

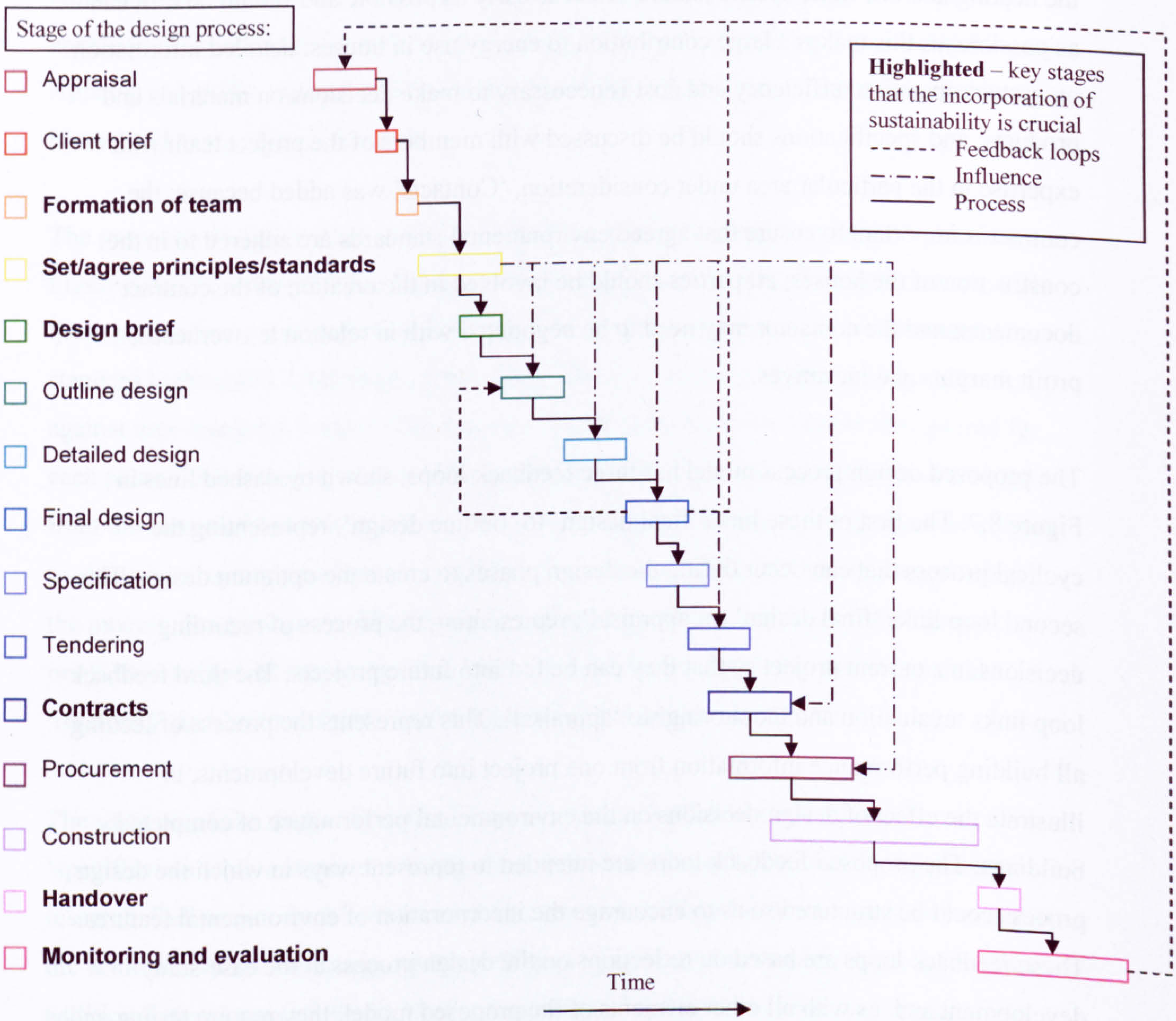


Figure 8.7: Enhanced model of the design process for low-energy housing

As noted above, the proposed design process model and accompanying lessons learnt draw on findings from previous literature, discussed in Chapter 2, as well as on the empirical work carried out for this thesis. For example, Macmillan et al. (2002) and Reed and Gordon (2000) found that interdisciplinary teamwork was needed from the outset of the project to assist the incorporation of sustainability, which is reflected in the 'formation of team' phase. Torcellini et al. (2005), Long et al. (2006), Horsley (2001) and Pearl (2004) all found that energy use needed to be addressed early in the design process, which is reflected in the 'set/agree principles/standards' phase. The work of Wallace (1987) and Long et al. (2006) informed the addition of the links from 'set/agree principles/standards' to future phases of the design process, as they found that revisiting the principles and staying committed to achieving performance goals was important. Watson et al. (2000) and Watson (2004) found that the design brief was vital for the reduction of a building's environmental impact. This is represented by the design brief being highlighted. The work of Watson (2004) and Mackinder and Marvin (1982) informed the feedback loop from 'final design' to 'appraisal', as they found that feeding decisions into future projects was very important to the learning process of project team members. Torcellini et al. (2005) informed the addition of the 'handover' stage, which includes the education of building operators on how to use systems efficiently so as to minimise energy use. The feedback loop from 'evaluation and monitoring' to 'appraisal' was informed by Andreau and Oreszcyn (2004) and Pearl (2004), who found that feedback from post-occupancy evaluation to the project team was beneficial in relating design decisions to building performance in use.

The successful implementation of the proposed model is likely to rely on all members of the project team using it, along with the additional accompanying lessons learnt, as a source of reference throughout the design process to help in achieving shared goals. Observation of the design process at the case-study development, however, suggests that such coordination among team members may be difficult to achieve. Section 8.3, p.217, summarises the stated motivations and the observed behaviour of some of the project team members involved in the design process at the case-study development. It is clear that different team members had different agendas and that this, at times, led to disagreements over decisions. It may be that use of a set of lessons learnt provided with the proposed model could help to promote agreement on goals and on how to reach them. This is an issue which could be examined in work to empirically test the model.

The present research has also shown that some members of the project team may have particular power to influence the design process in line with their priorities. One example was reported in section 6.9, p.164, with the contractor stating, in design team meeting 28, that the M&E consultants "didn't think humidity fans were a good idea". This led to the standard fan being chosen in construction meeting 9. It was also observed that certain members choose to exclude others from particular discussions. Section 6.7, p.156, for example, reported the project manager and contractor not involving the environmental consultant in the final selection of the heating and hot water system. The environmental consultant had initially specified this system to be as efficient as possible, to be high quality, and locally sourced, but despite his clear interest in this aspect of the development, he was not included in the final discussions.

Design team relationships may also influence the proposed feeding of information from 'Final design' and 'Monitoring and evaluation' into future projects. It may be that one member of the project team would need to be ultimately responsible for this, but to have the greatest affect the lessons learnt by all project team members would need to be captured, without bias towards any one point of view or preferred approach. This objective view of the design process may be very difficult to obtain. The present research has shown that members of a design team can have different priorities and motivations that dictate their behaviour. Despite these potential challenges the proposed model could be modified to help to form guidance for project team members developing low-energy housing.

The proposed design process model in Figure 8.7 develops the RIBA's *Plan of Work* (1998) to enable the delivery of low-energy housing specifically, rather than to give a general outline of the design process for any building type. The RIBA's *Plan of Work* was updated in July 2007, after the present research had been undertaken, so this latest version was not considered in the development of the proposed model. Table 8.2 shows the stages of the design process for the 1998 (Ibid) and the 2007 *Plan of* Work, as well as the model of the design process for low-energy housing proposed in the present research.

	RIBA (1998)	Beadle (2007)	RIBA (2007a)
Preparation	Appraisal Strategic brief	Appraisal Client brief Formation of the design team Set/agree principles/standards Design brief	Appraisal Design brief
Design	Outline proposals Detailed proposals Final proposals	Outline design Detailed design Final design	Concept Design development Technical design
Pre-Construction	Production information Tender documentation Tender action	Specification Tendering Contracts	Production information Tender documentation Tender action
Construction	Mobilisation Construction to practical completion	Procurement Construction	Mobilisation Construction to practical completion
Use	After practical completion	Handover Monitoring and evaluation	Post practical completion

Table 8.2: Comparison of the two RIBA design process models with the proposed model of the design process for low-energy housing

Table 8.2 shows that the updated *Plan of Work* (RIBA, 2007a) now has a 'Design Brief' stage, in place of the 'Strategic Brief' shown in the previous version (RIBA, 1998) used as the base-case for the present research. The only other difference between the two RIBA models is that the design stages have been renamed, with the latest version using 'Concept', 'Design Development' and 'Technical Design' rather than 'Outline Proposals', 'Detailed Proposals' and 'Final Proposals'. The renaming of these stages seems appropriate in light of the design process observed for this thesis, especially as the 'Technical Design' stage includes preparation of specification, which is an entire stage in the model proposed in the present research. The updated *Plan of Work* (RIBA, 2007a) does not specifically include any mention of elements to aid the development of low-energy buildings. The updated *Plan of Work* does, however, contain two aspects presented in the model proposed in the present research. Specification, as mentioned above, and "review of project performance in use"

(RIBA, 2007a, p.1) which is mentioned in the 'Post Practical Completion' stage and is similar to the 'Monitoring and Evaluation' stage in the model proposed here.

This section has presented the tentative proposed design process model for low-energy housing and has discussed the various sources that informed its development. Issues surrounding implementation of the model were also discussed, and a comparison of the proposed model with the updated *Plan of Work* (RIBA, 2007a) was presented. The proposed model is offered for use to help form guidance in conjunction with the accompanying lessons learnt for each phase of the design process; discussed and presented in Appendix H, p.281. Together, these materials could help to form guidance to assist members of the construction industry and housing developers in incorporating environmental standards into the design process. The model has, however, not been tested and is therefore a tentative proposal for consideration, which needs testing and further development before it could be used to form any sort of guidance.

8.6 Lessons, barriers and ways forward

In this section the lessons learnt from the case-study development are discussed, along with the barriers to delivering low-energy housing and how to overcome them, which were inferred from observations of the case-study design process. This discussion is based on data collected from the case-study development.

Overarching lessons learnt from the case-study development for future low-energy and zero-carbon housing came from many different areas of the design process. Principles and standards were set at the beginning of the design process and communicated to all involved via the *Project Execution Plan* (PEP) and the *Design Statement*, both distributed at design team meeting 5 (Briefing). Although these standards changed through the process, all parties knew that the aim was to achieve a high environmental standard and to build a 'sustainable' development. In meeting 5, working as a team, partnering and good communication were all noted as being important, but there was no formal agreement that any of these would take place. This meeting was the first time that the entire project team had come together to discuss the project, although it had been envisaged for several years prior to the meeting. Initial costs for the construction of the houses estimated by the contractor were 30% higher than the target cost as a risk premium had been added due to a lack of understanding about environmental features on the part of the contractor. The specification for many materials and systems was set by the architects and the M&E consultant to obtain the quality necessary to build sustainably. These specifications were, however, not always followed and many specifications changed during the construction process due to influences from the construction team. The locality and environmental impact of materials and services were taken into account for many items, but no constant guidelines were followed. The contract between the client and the main contractors included the achievement of the environmental standard. The final lesson to be learnt was that the design process for the case-study development took much longer than that for conventional houses, which needs to be taken into account at the outset of similar projects.

Throughout the design process at the case-study development there were barriers that were faced, some of which were overcome and some of which were not. This section looks at the barriers which were faced by the project team as a whole and by individual members. The contractor believed that his limited involvement in detailed design was a barrier to incorporating SIPs, which he felt was detrimental to the energy performance of the houses. This was not, however, felt by the rest of the project team who wanted to use traditional masonry construction techniques. Lack of knowledge of sustainable materials and systems was a barrier to the development of the houses as many opportunities to reduce the environmental impact of the houses were not realised. This was especially evident with the contractor, who estimated unrealistic prices for the construction of the houses and made assumptions about items without considering their environmental impact. Cost, especially affordability, was a barrier to delivering the case-study houses. This often seemed to be the primary motivation of the project team and was responsible for many of the compromises made in respect to the environmental standard. Another barrier was the lack of evidence showing that low-energy housing could be developed to be commercially viable. This lack of evidence also had an influence on the revision of the original zero-heating standard.

External agencies were seen as barriers to the development of the case-study houses. These included the County Council's highways and planning departments as well as the local water company. A barrier to developing low-energy housing throughout the UK was discussed by the structural and infrastructure engineer, who stated that mainstream housing developers are in no way driven by the sustainability agenda.

The increased cost of the environmental standard was a barrier to its achievement. This could, however, be resolved in one of three ways. The first is for the housing developer to reduce their profits, which was the solution in this project. The case-study developer reduced profits from around 30% to 20%. The second is for the houses to be more expensive to buy, which would mean the house buyer was investing more in the house in capital costs for reduced running costs in the future. The final way is for the government to subsidise these additional costs. The government was seen by project team members as both a barrier and a way to overcome barriers to the development of low-energy housing. The government was not seen by the project team members to be doing enough to support the delivery of low-energy housing through Building Regulations and it was thought planning policy needed to be more stringent in both content and enforcement. It was suggested that the government could resolve these problems by investing more money in the development of low-energy and zero-carbon houses as well as improving the Building Regulations and planning policy, and making sure these were met by all developments. The construction industry was the final entity seen by project team members as both a barrier and a way to overcome barriers, in that certain members of the project team were seen as needing to change the way they do and think about things, in particular the contractor. It was also stated by project team members that the quantity surveyors and the bank needed to change the way they worked to help enable low-energy projects. The issue of construction quality was also seen as a barrier, but could be overcome if focused on and addressed during construction by those in the construction team responsible for the quality of the work.

Increasing the knowledge of project team members about the different aspects of low-energy housing will enable them to make better informed decisions which will reduce the environmental impact of the project. This could be achieved by lectures, workshops and visits for all parties involved in the project. When the project team is formed, partnering helps the team to commit to shared goals and have a sense of shared responsibility to achieve the principles of the project. The M&E consultant stated that as planning permission has become harder for housing developers to obtain, they were becoming more interested in incorporating environmental strategies into their projects to help them gain planning permission.

A way to overcome risk premiums can be achieved by simply investigating all costs reported to ensure that a cost premium has not been added. This could involve collecting several quotes and challenging all estimates made. The best solution to delivering low-energy housing may be the involvement of individuals and organisations that have been through the design process for low-energy housing, as they will have climbed a learning curve through being involved in projects and experiencing challenges, difficulties and barriers. This experience and feed back to project team members after the completion of a project needs to be addressed at the beginning of the design process, so that mechanisms for its implementation can be put in place.

Barriers and ways to overcome them were found throughout the design process and involved the entire project team. The barriers observed all have their own solutions, but many of these would require changes in government policy and how developers and the construction industry work. This will take some time, but the beginnings of some of these changes are being observed and as climate change becomes more salient for the public, there should be a demand for action.

8.7 Chapter conclusions

This chapter presented lessons learnt, barriers and solutions to delivering low-energy housing, which were found throughout the design process and involved the entire project team. This chapter has presented a discussion of findings from the present research and has sought to integrate these with insights from previous literature. The predicted environmental standard to be met by the case-study houses was just below EcoHomes excellent, which is equivalent to level 3 of the Code for Sustainable Homes. It is argued that the development could have achieved EcoHomes excellent, but in the late stages of the design process this would have involved extra monetary investment. This environmental standard was much lower than that seen in the original concept for the houses, due to a number of factors outlined in section 8.2. This chapter showed that the project team members at the case-study development generally acted in ways consistent with the motivations stated when they were interviewed.

Individuals involved in other design processes, when asked, indicated that a design process model for low-energy housing, with related guidance on how to use it, would assist them in lowering the environmental impact of housing developments on which they worked. A new design process model was tentatively proposed to help form guidance to enable the delivery of low-energy housing. This model is based on observation of the case-study development, design team questionnaire data, and findings from previous research. While the proposed model incorporates findings from the present research, such as the need to reinforce the environmental standard during the outline, detailed and final design stages, it does not take into account the individual motivations and behaviour of project team members. The issues caused by these members and their power relationships suggest that any new design process model may not be capable of dealing with these problems. These team-specific characteristics will inevitably vary from development to development. It is stressed that the proposed model is a tentative synthesis of lessons from the case-study data, previous literature and the questionnaire with project team members discussed in the present thesis. It needs to be tested and evaluated through application in future developments before it can help form any sort of guidance. Lessons learnt to accompany the proposed model are presented in Appendix H, p.281.

9. Conclusion

This chapter concludes the present thesis summarising the extent to which this research has achieved its objectives, highlighting the original contribution to knowledge and suggesting applications for the research. Questions for policy to address to enable the delivery of low-energy housing developments are then presented. This is followed by a brief overview of the limitations of the research and the final section suggests areas of future research to better enable the development of low-energy and zero-carbon housing.

9.1 Achievement of objectives

The aim of this research has been to achieve the research objectives set out in Chapter 1 (section 1.1, p.11). These objectives are restated and the extent to which they have been met is summarised in this section.

1. To evaluate how the design process for the case-study development studied differs from conventional design process models.

Chapter 5 addressed this objective by providing an overview of the differences between the design process described in the present thesis for low-energy housing and that of a conventional design process model, the Royal Institute of British Architects' (RIBA) *Plan of Work.* The findings showed that environmental impact was not addressed in the *Plan of Work* and that it needed to be dealt with during the design process to enable the development of low-energy housing. Several additional phases were proposed to the *Plan of Work*, by the author of the present thesis, to encourage reductions in environmental impact. These included: formation of the design team; set/agree principles/standards; design brief; contracts; and procurement. The resulting modified design process for low-energy housing was proposed in Chapter 8 (section 8.5, p.227) and included another additional stage; monitoring and evaluation. The three tendering stages were also combined and the most important phases for reducing environmental impact were highlighted. These were: formation of the design team; set/agree principles/standards; design brief; contracts; handover; and monitoring and evaluation. Feedback loops and influence links were also proposed to highlight that the process is not linear. The proposed model was informed by the data collected during the research and findings from previous studies.

The present research has, however, shown that the proposed design process model may not necessarily have an impact on the motivations, attitudes and behaviours of the project team members. Therefore it may not affect the environmental impact of any housing built using it. This is explored in more detail in section 8.5, p.227 and in the response to objective 4 below. The research has highlighted the significant influence of the dynamics, interactions and perspectives of various project team members. This has resulted in some of the original objectives that relate to the design process model serving as a catalyst to the research findings rather than informing them directly.

2. To investigate how decisions made within the design process affect the economic, social and environmental characteristics of the houses in a large-scale, private-sector, low-energy housing development.

Chapter 6 addressed this objective by providing an overview of the effect that decisions made in the design process had on the economic, social and environmental characteristics of the case-study houses. The biggest influence on the decisions was the EcoHomes standard, which was referred to throughout the process. The implications of this standard affected the economic characteristics of the houses by increasing cost, due to the time needed for the design process and the quality required. Motivations of the project team were discussed in Chapter 7 (section 7.4, p.184) and showed that cost, especially affordability, and environmental impact were the most significant influences of their decision making. Cost was highlighted as the main influence as compromises were made with the environmental standard because of cost constraints. The social effects of the decisions made have enabled the houses to reduce the energy costs for residents and offer opportunities for living in a mixed-use development. Although the environmental standard set for the project guided most of the decisions made, the initial standard was compromised, but this enabled the development to be commercially viable and could facilitate the next step in mass housing production.

3. To evaluate the decisions made at the case-study development to maintain its commercial viability.

This objective was addressed in Chapter 8 (section 8.2, p.213), which provided an overview of the compromises made at the case-study development to ensure its commercial viability. These compromises were all in relation to the environmental standard. At one point this standard was based around zero-heating which reduced to just below EcoHomes excellent when the present thesis was submitted (September 2007). The compromises which drove the standard below EcoHomes excellent were largely due to changes in material and system specification during construction, driven by cost. Cost and unfamiliarity were the reasons that the zero-heating standard was not pursued. This standard would be feasible in the future if: perceptions about zero heating change; the cost of achieving zero heating is seen as beneficial and having a 'market value'; and the knowledge of those delivering the standard increases.

4. To investigate whether a new model of the design process for low-energy housing is necessary and, if so, how observations of the case-study design process can be combined with previous research findings to create such a model.

Section 8.4, p.223, reports a survey of project team members' views on the design process. This revealed that the RIBA *Plan of Work* did not encourage sustainability to be incorporated into the design process (although admittedly it was not designed with this aim). It was suggested by survey respondents that a new model of the design process for low-energy housing would be helpful, along with guidance in the form of a checklist. However, the results from the present research have shown that a new model may not necessarily encourage the development of low-energy housing. This discrepancy is explored in the following paragraphs.

A design process model for low-energy housing was presented in Chapter 5 (section 5.8, p.122) and was enhanced using analysis of data presented in Chapters 6 and 7. This analysis was combined with findings from previous research and presented in the proposed design process model provided in Chapter 8 (section 8.5, p.227). This model (or any other), however, may not necessarily lead to the achievement of low-energy housing. The present research showed that project team members may have conflicting motivations and priorities which would mean that working to a new model, such as the one proposed in this thesis, may require considerable compromise. The present research has also shown that some project team members have more power than others to promote their interests through presenting situations in a particular way, or through excluding other members of the team from particular meetings, as discussed in section 8.5, p.227.

Another potential barrier to the implementation of a new design process model is the way in which such models are currently used by project teams. Many members of the project team are involved in different stages of the design process, but it is usually the project manager and client who see the building through the entire design process, which suggests that they would need to be involved in the implementation of any new design process model. This could be difficult because they are only two of a number of people involved in the process. If they were solely involved in the implementation of the model it could reflect their motivations and drivers and be somewhat biased because of this.

The results presented in this thesis could form guidance for members of the project team seeking assistance in delivering low-energy housing. However, the results would need to be strengthened by collecting and analysing similar data at other low-energy and zero-carbon developments. It may also be that project team members would need a prior interest in sustainability in order to use any guidance successfully and any other information provided.

However, any guidance given may encourage greater interest in and understanding of sustainable design and construction. This is an issue for future research.

The work has shown that a new design process model in isolation would not necessarily enable low-energy housing to be delivered because of the attitudes, motivations and power of the project team members involved.

> 5. To use any new knowledge and understanding gained from this research to provide guidance to those involved in delivering low-energy housing to enable high environmental standards to be achieved.

The three results Chapters (5, 6 and 7) and the discussion Chapter (8) have provided a great deal of new knowledge and understanding about the design process of low-energy housing. This has been summarised in the conclusions to each of the results chapters as well as in the lessons, barriers and ways forward presented in Chapter 8 (section 8.6, p.234). This new knowledge and understanding has been combined with previous research and the questionnaire for project team members to provide a set of lessons learnt, presented in Appendix H (p.281). This could be used in future research to develop more accurate guidance.

The insights identified from addressing the research objectives represent part of the original contribution to knowledge made by the present thesis. In addition, the extensive detail provided about a real case-study design process in Chapters 5 and 6 illustrates the complexities of the process. In Chapter 5, six factors that were identified as being key to the incorporation of the high environmental standard into the design process at the case-study development were analysed. In Chapter 6, eight decisions that affected the environmental impact of the houses on the case-study development were identified and investigated. These chapters used data from design team meetings, documents distributed at these meetings and construction meetings. Such an in-depth description and analysis of a real design process does not exist in any of the literature reviewed by the author. The comparison between the project team members' stated motivations when interviewed and their behaviour during the design process, discussed in section 8.3, p.217, also adds to the original contribution of knowledge as it provides a unique insight into the motivations of project team members and the interrelationships between them.

The information and findings from the present thesis need to be communicated to all those involved in the development of low-energy housing, including: members of the construction industry; housing developers; and policy makers. These findings will be of particular interest to the English Partnership's (EP) Carbon Challenge, which aims to create a number of zero-carbon communities on behalf of the DCLG (Department of Communities and Local Government) (EP, 2007). The work will also be of interest to the government's zero-carbon homes initiative, of which the Carbon Challenge is a part, as well as other future low-energy and zero-carbon housing developments. A summary of the present research will be created and disseminated to some of the parties listed above to help enable them to develop low-energy and zero-carbon houses.

9.2 Questions for policy makers to address

The present thesis has led, through reflections on the findings from the observed case-study design process, to questions that could be addressed by policy makers to encourage the development of low-energy and zero-carbon housing on a large scale. In this section these questions are presented along with justification of the need to ask them, from evidence gathered during the present research. The questions are grouped under six categories: cost; knowledge; standards; materials/products; relationships; and the construction industry.

Cost

- *Who is going to fund the inevitable increase in building new houses in the UK to higher environmental standards, such as zero carbon? Which of three main sources will provide this money: government, developers, or house buyers? Or does the development of new housing need to be completely reorganised to provide more affordable housing?* This question has been posed as cost was the main barrier, cited during interviews with project team members, to the development of the case-study houses, shown in Chapter 7.

Knowledge

- *How do decision makers involved in the design process of low-energy housing increase their understanding of environmental features and the associated costs?* The need for this to be addressed was shown during the design team meetings at the case-study development, as there was a distinct lack of knowledge in many areas relating to environmental features. Examples of these include: the cost of non-PVC wiring; the benefits of wet plaster; and the specification of the heating and hot water system. These were discussed in Chapter 6 of the present thesis, which addressed decisions that related to the environmental impact of the case-study houses.
- *How do decision makers involved in the design process for low-energy housing learn from their decisions? Is feedback from low-energy housing projects needed after monitoring and evaluation is undertaken to see the outcomes of decisions made?* The decision makers at the case-study development did not understand the consequences of their decisions in relation to environmental impact. This was shown in Chapter 6, when an alternative boiler was specified by the contractor and agreed to, by the project manager and the client, without knowing its performance.
- *How can evidence that low-energy housing developments can be delivered be provided to developers?* This was seen as a barrier to delivering low-energy housing by the project manager at the case-study development, when interviewed.
- *How can external agencies, such as the planning department, the highways authority and the local water companies, be informed about the issues involved in developing a low-energy housing development?* These agencies were seen to have a lack of understanding about several elements of the case-study development, which was evidenced in Chapter 7, when several members of the project team interviewed stated that they were a barrier to the development of low-energy housing.

Standards

- *How do decision makers ensure that principles and standards are set at the beginning of the project and that all stakeholders involved in the project adhere to these?* The need for this question is shown in sections 5.2 and 8.2, as standards and principles were set at the beginning of the design process at the case-study development, but were renegotiated and different members of the project team seemed to be working towards achieving different standards.
- *How can planning conditions be enforced to provide exemplar low-energy housing developments?* The planning conditions set for the case-study development, which included the zero-heating energy standard as well as the provision of renewable energy technologies, were renegotiated, as discussed in section 6.1.

Materials/products

- *How do decision makers compare the energy use of a product or material over its life cycle? Is life-cycle analysis of all products and materials needed so that the most sustainable choices can be made?* This was evidenced at the case-study development as it was often difficult to identify the products and materials with the lowest environmental impact. Examples of this, discussed in Chapter 6, included: insulation; recycled materials; rainwater goods; cavity closers; and wall ties.

Relationships

- *How can better partnering and working relationships be encouraged in the design process of low-energy housing developments?* The relationships worked at the case-study development because of previous working relationships that had been formed, as evidenced in section 7.3 of the present thesis. This would not always be the case on other low-energy developments and therefore needs to be investigated further.
- *How can local authorities involvement in the design process of low-energy housing be more integrated?* Relationship between the local authority and the project team members at the case-study development was disjointed, this arose from the following issues: both parties had different drivers; the local authority wanted many

aspects of the development to be like a conventional development; strict standards were set by the local authority which conflicted with environmental features on the site; and the local authority didn't understand the drivers or principles behind the case-study development. These issues were outlined in section 6.7.1 and caused severe delays and tension between the two parties.

Construction industry

- *How can the construction industry adapt how it works to enable the delivery of low-energy housing?* The need for the construction industry to change was shown in Chapter 7, where several project team members, when interviewed, described the construction industry as being a major barrier. The reasons for this included: the mindset of certain members of the industry; the traditional/conventional focus; the way they work; and the lack of knowledge about environmental features.

9.3 Limitations

The main limitation for this research was that only one case-study housing development was investigated. However, the nature of INREB (Integration of New and Renewable Energy in Buildings) Faraday Partnership, funded by the EPSRC (Engineering and Physical Sciences Research Council) as an industrial CASE (Cooperative Awards in Science and Engineering) studentship meant that this was not feasible. This provided the unique and almost unrestricted access to the design process at the case-study development. The progress of the case-study development did, however, dictate the research that could take place. This meant that the time delays experienced by the development prevented the author from conducting some planned additional studies at the case-study development. The time delays were so severe that the first phase of the houses, which was scheduled to be completed by Easter 2006, was not completed before the present thesis was submitted in September 2007. The additional studies would have investigated:

- The attitudes of prospective house buyers towards the case-study houses, energy efficiency and renewable energy.
- The energy performance and airtightness achieved at the case-study houses when built, which could have been compared to the predicted values.
- The attitudes of residents towards the case-study houses and their behaviour and energy consumption as householders.

These limitations did mean, however, that the research was much more focused on the design process for the houses and that the data collected from the 34 design team and nine construction meetings could be analysed thoroughly to reveal the results presented in the present thesis.

The fact that the energy performance of the houses was not monitored was a significant limitation as it is the most quantifiable measure of the development's success, in terms of environmental impact over the life of the houses. Although the predicted environmental standard for the case-study houses was evaluated, discrepancies could have occurred between this and the actual houses as built. Another limitation was that the relationships between the project team members were not investigated further and so a full understanding of how the project team worked was not presented. An investigation of the dynamics between the project team members would have identified to what extent certain relationships affected the process. A study of the existing relationships between project team members at the case-study development could have shown if the design process would have been as successful without these relationships being formed before the start of the project.

Knowledge and understanding of the project team, about environmental features, was very important to the case-study development and the delivery of the high environmental standard. A limitation of the study was that this was not investigated further. Interviews with project team members were only undertaken towards the end of the design process. If they had been conducted at several points throughout the design process, the knowledge and understanding of the project team members could have been tracked to see how it developed over time. This would have enabled the deficiencies in this knowledge to have been identified and even addressed during the early stages of the design process. These interviews were not undertaken as the client insisted that they wait until contracts were in place.

9.4 Future work

From this research, topics for future work to enable the development of low-energy and zero-carbon housing are identified. These lead on from the previous section and could form a programme of research for the next ten years. Developing detailed ideas for further conceptual work has proved challenging because the findings from the present research do not align with the initial expectations. These expectations, reflected in some of the objectives set, were that a new model of the design process would enable the project team to successfully deliver low-energy housing. The findings showed that a new design process model would not necessarily enable low-energy housing to be delivered due to the motivations, attitudes and interactions of project team members. Further investigation of these issues is discussed in this section. The suggestions for future work are grouped into three categories: dissemination of present research; further research about the case-study development; and further research using other case studies.

Dissemination of present research:

- To inform those involved in the design process for low-energy housing of the lessons learnt, barriers and how to overcome them presented in this research.
- To inform project team members at the case-study development and beyond of the decision-making process for elements that affect the environmental impact of houses.

Further research about the case-study development:

- Relationships

- Qualitative content analysis of the data collected from observations of the design process could be undertaken to investigate the interactions between project team members. This was undertaken by Wallace (1986) and Gorse et al. (2001) and is discussed in section 2.5.3, p.44.
  - Investigation of the relationships between project team members to understand how the project team at the case-study development worked.
  - Investigation of who was responsible for making decisions, especially those that relate to the environmental impact of the houses and what effect this had on the outcome of the decisions.
  - Investigation of the hierarchy that existed when decisions were made to better understand the decision-making process.

- Attitudes
  - Questionnaire survey of prospective buyers of the case-study houses:
    - To assess their attitudes towards the low-energy houses, energy-efficiency and renewable energy.
    - To inform future phases of the case-study development.
    - To inform policy makers and members of the construction industry of what needs to be done to improve and deliver low-energy housing.
    - A questionnaire survey for prospective buyers was designed during the research, but was not implemented due to the time delays experienced. This could be reviewed and revised and used in the show homes of the case-study development.
  - Interviews with residents of the case-study houses:
    - To assess their attitudes towards the low-energy houses.
    - To assess their behaviour in the low-energy houses and what affect this has on the energy performance of the houses.
    - To inform future phases of the case-study development.

    - To inform policy makers and members of the construction industry of what needs to be done to improve and deliver low-energy housing.
  - An interview schedule, consisting of a list of questions under several categories, could be developed and interviews undertaken to investigate the attitudes of residents within the case-study houses. The data from these could be cross referenced with energy performance data to provide an in-depth analysis of household energy use of the case-study development.
- Monitoring
  - Evaluation of the environmental standard achieved at the case-study development, to compare with the predicted assessment evaluated in the present research.
  - Airtightness testing on the case-study houses to assess the quality of the building construction according to the Building Services Research Information Association (BSRIA, 2007).
  - Energy monitoring of the case-study houses to:
    - compare the predicted energy consumption of the houses with the actual energy consumption.
    - identify possible reasons, from the data collected, for any discrepancies in the predicted and actual energy consumption; this would be linked with the interviews of occupants, described above.
    - learn lessons about decisions made during the design process that could be fed back to the project team members involved and the wider construction industry to inform future projects.

The future work suggested for the case-study development could be undertaken for all phases of the case-study development up to and beyond when the housing development is due to be completed in 2010. This would provide a longitudinal investigation of the entire development and would enable lessons learnt throughout the development to be fed back to project team members at the case-study development and the wider construction industry. The implications of decisions made in earlier phases could also be seen through energy consumption data and interviews with residents.

Further research using other case studies:

- The results from the present research could be enhanced by collecting and analysing similar data to that collected at the case-study development, from other low-energy and zero-carbon housing developments. This would help to build on the understanding gained from the present research and help to provide guidance that could inform policy. The following points would need to be considered if this was undertaken:
  - Unrestricted access would be needed to the case-study design process. Data would be collected from the case-study design processes in a similar way to the present research, although action research could be used. Action research has some problems associated with it, outlined in section 4.4, p.77, these would be outweighed by the ability to influence the design process.
  - English Partnerships are organising the development of the government's zero-carbon house initiative through a series of Carbon Challenge case studies. These should be valuable for gaining knowledge as the client is government-related and should therefore want to learn as much as possible from the first large-scale zero-carbon developments in the UK.
- The future work proposed, and that undertaken at the case-study development for the present research, could be undertaken on any future case studies investigated.
- Future research conducted at low-energy and/or zero-carbon housing developments could build on the present research and give important insights into issues raised by the research that were not investigated fully. The following

questions raise issues that if understood better and dealt with appropriately, could help lead to the delivery of low-energy and zero-carbon housing developments:

- How do project team members interact within the design process and what affect does the dynamic of the team have on their individual behaviour?
- What power relationships can be seen during the design process and how can these be managed to help deliver low-energy and zero-carbon housing developments?
- What are the motivations of the different project team members in the design process and how do these affect the interactions in the design process and the decision making processes of the team?
- What influences and pressures are there on project team members from external sources to the design process and how does this affect their behaviour?
- How can the knowledge and understanding of project team members be assessed at the beginning of the design process in order to identify future training needs?
- What sort of training can be provided for project team members to enable a low-energy or zero-carbon standard to be attained and how would it be implemented?

The government's zero-carbon housing agenda will make the importance of this research more urgent as we get closer to 2016, when the government requires all new housing to be zero-carbon.

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Appendix A: Matrix of project team members' attendance at design team meetings

	Design Team Meetings																																												
Project Team members	1	2	3	4	5	5a	6	7	8	9	9a	10	11	11a	11b	11c	12	12a	12b	13	14	15	16	17	18	19	20	21	21a	21b	22	23	24	25	26	27	28	28a	29	30	31	32	33	34	Total
Client (main)	√	√	√	√	√	Data not available	√	√	√	√	Data not available	√	√	Data not available	Data not available	Data not available	√	Data not available	Data not available	√	√	√	√	√	√	√	√	√	Data not available	Data not available	√	√				√	√	Data not available	√	√	√	√	√	√	32
2nd Client	√		√		√		√		√	√		√								√	√	√	√			√																			12
Project manager	√		√	√	√		√	√	√			√	√				√			√	√	√	√	√	√		√	√			√	√	√	√	√	√	√		√	√	√	√	√	√	32
Principal architect	√	√		√	√		√						√																																6
Job architect					√		√	√	√	√			√				√					√	√		√	√	√						√		√										14
3rd Architect					√												√			√			√	√	√	√																			7
4th Architect																																	√				√			√				√	4
Safety officer					√																																								1
2nd Safety officer																																												√	1
Contractor																	√			√				√				√			√	√	√	√	√	√	√			√	√	√	√	√	17
2nd Contractor					√																																								1
3rd Contractor					√																																								1
4th Contractor (site foreman)																																		√	√		√							√	4
Mechanical and electrical (M&E)					√								√							√																									3
2nd M&E																										√	√							√											3
Structural and infrastructure engineer					√															√							√								√									√	5
Quantity surveyor					√																																								1
Selling agent					√		√	√	√																																				4
2nd Selling agent									√																																				1
Civils contractor																																												√	1
2nd Civils contractor																																												√	1
Water consultant					√																																								1
Researcher	√	√	√	√	√		√	√	√	√		√	√				√			√	√	√	√	√	√	√	√	√			√	√	√	√	√	√	√		√	√	√	√	√	√	34

Appendix B: Summary of design team meeting 28

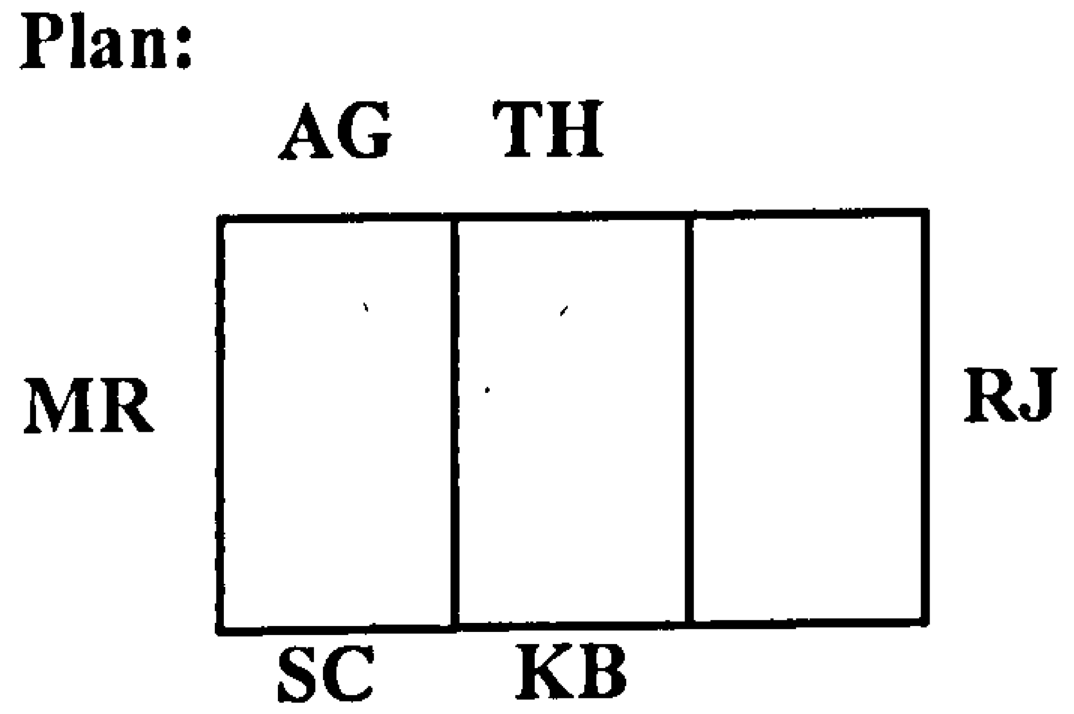
Summary - Design Team Meeting (28)

22nd June 2006
13:50 – 16:30 hours

Attending: AG (project manager), SC (main client), RJ (main contractor), MR (foreman), TH (fourth architect) and KB (researcher)

Location: JDA Offices

Seating Plan:



Documents distributed: Meeting notes from meeting 06/06/2006

Documents referred to: Type B house type plan
Eve and verge details
Internal door catalogue
Skirting details

Summary: This meeting consisted of a run through of the notes from the meeting on 06/06/2006 that looked in detail at every aspect of the houses and what decisions still had to be made on each. This meeting was for SC to make decisions on some aspects of the houses and to confirm those that had been made in his absence. These covered several areas: drawing clarification; issues raised on type B; value engineering; and a review of the decisions made in the meeting with GD Woodworking. A review of the meetings with the heating and plumbing consultants and the electrical consultants were undertaken. It was also decided that the next two weeks would be used to sort out all issues that needed to be clarified before construction. A meeting for the 4th of July was scheduled in this period, just to check that everything was on track and that all boxes were ticked.

Next Meeting: Tuesday 4th July 2006, 09.30, E-centre

Appendix C: Semi-structured interview for project team members at the case-study development

Interview introduction:

There will be three main parts to the interview. Firstly I will ask you a few general questions about your background, your opinion on the project and the standard that the houses are to be built to. Secondly, I will go on to ask some questions about the design process, design decisions, any lessons learnt and barriers faced. Finally there is a check-sheet of questions that I would like you to fill in that will give general demographic information as well as looking at your attitude towards the house designs and the environment. This will give additional value information to help me to understand what's influenced the decisions that have been made.

Please answer all questions in as much detail as possible.

You are free to withdraw from the interview at any time and to skip any questions that you do not want to answer. The interview, with your permission, will be recorded on this digital voice recorder and will be transcribed. This transcription will be available for your verification.

Some of the questions may seem difficult to answer or irrelevant, as some may only be appropriate for certain people within the design team. There are no right or wrong answers, so please respond as best you can.

Please feel free to interrupt, ask for clarification or criticise a line of questioning.

The interview shouldn't take more than one hour.

Do you understand everything explained so far? And are you happy to make a start?

Interview Questions:

Background information

1. What would you say your role is within the design team (a title and a quick run-down of duties)?
2. What is your previous experience of low-energy projects, if any?
3. Why did you and your organisation want to be involved in this project?
    a. How long have you been involved?
    b. How did you get involved?

The project and standards

4. From your point of view, what do you think are the key issues involved in this project?
5. What were your initial thoughts about the high environmental standard wanted for this project?
6. Focusing on the standard set for the project (EcoHomes excellent), what would you say the key elements are for the successful implementation and delivery of this standard?

Design decisions

7. How do you think the design process for this project has differed from other more conventional design processes?
    a. Time
    b. Costs
    c. Additions to the process
    d. Order of stages
    e. Different stages
    f. Briefing
    g. Detailed design
    h. Tendering/procurement process
    i. Your involvement

j. The involvement of others

k. ...

l. ...

8. What do you see as the key design decisions that have been taken in this project?
9. What would you say motivates the decisions you make (or help to make) within the design process?
10. What do you think have been the key influences that have shaped the decisions made by the design team as a whole?
    a. Would you say that your views were difficult to get across?
    b. Would you say that your views were shared by the majority of people in the team?

Lessons and barriers

11. What would you say the main barriers to building low-energy houses are?
12. How have these barriers been overcome on this project?
13. What lessons do you think have been learnt from this project about designing and building low-energy housing?
14. Are you or your organisation going to take anything learnt about low-energy building from this project onto future projects?
    a. If this is the case, what?
    b. Have any of your processes changed as a result of this project?
    c. Have any of your policies changed as a result of this project?

Thank you very much

Finally...

Do you have any other comments regarding any questions that have been asked or any other issues you would like to discuss?

Thank you very much for your time.

I may like to have the chance to interview you again in the future as the houses at SEV progress, please let me know if this would be ok.

If you would like to find out more about the research or receive a copy of any pieces of work, then please feel free to contact me at kbeadle@dmu.ac.uk.

Appendix D: Final template for analysis of data from the design team meetings at the case-study development to identify issues relevant to the research objectives

Final Template - 18/12/2006			
1st order codes	2nd order codes	3rd order codes	4th order codes
Contracts	Legals		
	Time		
	Contract document	Pre-ambles	
		Preliminaries	
		Type	
	Finance	Provisional sums	
		Procurement	
	External actors	Bank	QS
			Valuers
		EP	
		EMDA	
Costs	Standards	EcoHomes	
		Beyond EcoHomes	
		Conventional developers	
		Premiums	
		SEV board	
	Construction	House designs	Third storey
			Apartments
		Contractor	
		Build cost	
		Provisional sums	
		Value engineering	
	Materials		
Principles	Setting		
	Revising	Revisiting	
		Reinforcing	
Project Team	Core design team		
	Members		
	Workings		
	Contract team		
	Sales and marketing	Sales	
		Marketing	
	Communication	SEV board	Board
			AGM

		Buyers
		Meetings
	Partnering	
	Conflicts	
Procurement	Materials	
	Supply chain	Sub-contractors
	Approach	Strategy
Tendering	Packages	
	Bills of quantity	
	Infrastructure	
	Labour	

The elements that are underlined are headings for sections that also contain data for analysis.

Appendix E: Final template for analysis of data from the design team meetings at the case-study development to identify decisions made that related to the environmental impact of the houses

Final Template - 22/01/2007			
1st order codes	2nd order codes	3rd order codes	4th order codes
Heating/Hot Water	Solar	System	
		Space considerations	
		Planning	
	Other aspects	Boiler	
		Shower	
		Radiators	
	Fires		
Insulation	Acoustic insulation standard		
	Insulation standard		
	Cost implications		
	Selecting manufacture/type		
	Insulation in construction	Perimeter	
		Roof	
		Internal walls	
Materials	Specification	Performance	
		EcoHomes	
	Timber	Timber policy	Type
			Treatment
			Waste issues
			Building elements
		EcoHomes	
		Procurement	
	Recycled materials		
	Sourcing (local materials)		
Building Elements	Finishes	Plaster	
		Paints	
	Windows	Glazing	
		Cavity closer	
	Construction	Tek construction	
		Wiring	
		Damp proof course	

		Lintels	
		Rainwater goods	
		Wall ties	
		Floors	
Water	Drainage	Systems	
		Technical solution	
		EcoHomes	
	Rainwater harvesting	Systems	
		EcoHome credits	
	Water consumption	EcoHome credits	
		Features	
Ventilation	Fans		
	Passive stack		
	Roof		
Lighting	Daylighting	Windows	
		EcoHomes	
	Electric lighting	Low-energy lighting	Type
			VIP lighting pack
		External	
		LEDs	
Standards	EcoHomes	Scoring	
		Achieving excellent	Drying space
			Bike parking
			White goods
			Private space
		Credits	
		Assessment	
		Problems/issues	
		Costs/premiums	
	Beyond excellent	Metering and monitoring	Monitoring
			Meter boxes
		Secure by design	
	Zero-heating	Concerns	
		Planning issues	
		Costs	
	Examples	Codes	AECB
			Code for Sustainable Homes
		Projects	
	Management committee	Covenants	
		Examples	

		Planning	
Renewable Energy	EcoHomes		
	Funding opportunities	Clearskies	
		PV	
	Heating systems	GSHP	
		Biomass	
	Technology		
	PV canopies		

The elements that are underlined are headings for sections that also contain data for analysis.

Appendix F: Final template for analysis of data from interviews with members of the project team at the case-study development

Final Template - 5/3/2007			
	2nd order codes	3rd order codes	4th order codes
Environmental standards	Published standards	EcoHomes	Excellent
			Problems
			Approach
		Code for Sustainable Homes	
		AECB	
	Concepts in housing	Energy efficient	
		Zero-heating	
		Zero-carbon	
	SEV	SEVHomes	Future phases
			Purchasers extras
		Original conception	
		Planning conditions	affordability
		Construction	
		Cost	
Elements of the design process	Detailed design	Components	Bathrooms
			Kitchens
			Tiles
			Rain water goods
			Wiring
			Garages
			Boiler
			Bricks
		Renewables	Solar
			Wood-burning stove
		House designs	
	Outline design	Style	
		Densities	
		House types	
		Quality	
		Street scene	
	Design brief		
	Construction	SIP	
	Timing		

Project team motivations	Internal	Interest	
		Feel of a normal house	
		Finance	Profit
			Business case
			Affordability
			Win work
		Getting to site	
		Sustainability	Standards
			Environmental
			Spread the word
			Performance
			Community
		Adoptability	
		Quality	Design
			Materials
		Demonstration	
		Locality	
		Vision	
		Pride	
	External (perceived)	Finance	Profit
			Affordability
		Aesthetics	
		Sustainability	Community
			Environmental
		Adoptability	
		Quality	
		Pride	
		Best techniques	
		Locality	
Barriers and Solutions	Barriers	External agencies	Highways
			Planning
			Severn Trent
		Cost	
		Industry	
		Lack of examples	
		Government	
		Knowledge	
		Changes to design	
		Time	
		Involvement	
	Solutions	Demonstration	
		Understanding	
		Government	

		Industry	
		Design team relations	
Lessons learnt	Quantitative	Design details	
		Cost	
		House types	
		Time	
	Qualitative	Formation of design team	
		Relationships	
		Personal characteristics	Knowledge
			Open mind
	Future lessons		
Project team workings	<u>Partnering</u>	Open discussion	
		Trust	
	Introductions		
	<u>Involvement</u>	Risk	
	Choice of company	Contractor	
		Architects	
	Expectations		
	Role/responsibility		
Project team's knowledge and experience	Experience	Commercial buildings	
		Leisure accommodation	
		<u>Housing</u>	Social
			One-off
			Demonstration project
		<u>SEV</u>	Credit League
			E-centre
			JDA
		Business	
		Factory units	
	Knowledge		

The elements that are underlined are headings for sections that also contain data for analysis.

Appendix G: Questionnaire for project team members

The Design Process for Sustainable Houses: Questions for design team members

This questionnaire is part of PhD research conducted by Katy Beadle at the Institute of Energy and Sustainable Development, De Montfort University, Leicester. The aim of the research is to investigate the design process for sustainable housing, to help with its delivery. The information collected from this questionnaire will form a vital part of the discussion chapter for the PhD thesis, which should be published before the end of 2007. The data collected will be used for this PhD thesis and other research dissemination, but you and your organisation will not be identified in any of these publications.

Please complete and return this questionnaire to Katy Beadle (kbeadle@dmu.ac.uk) by Friday 13th July, if possible. She will be happy to answer any questions or provide you with more information about her research. Please use another page to answer the questions if necessary.

Questions:

1) What is your profession? [ ]

2) Do you use the RIBA *Plan of Work* to guide projects you work on? Yes No

2a) If yes, do you think that it helps you to incorporate sustainability into these projects? Yes No

3) Do you use any other guidance to assist with the incorporation of sustainability into projects? Yes No

3a) If yes, what do you use and why?

[ ]

4) Would you find a model of the design process that highlighted relevant considerations and gave guidance about the incorporation of sustainability useful when developing sustainable buildings, especially housing? Yes No

4a) If yes, what form would you like this in? (eg: flow chart, list etc.)

[ ]

5) How do you think the design process for sustainable housing (or other sustainable buildings if you don't have experience of houses) differs from that of conventional houses?

[ ]

6) What do you see as the barriers and solutions to developing sustainable housing (or other sustainable buildings if you don't have experience of houses)?

[ ]

Thank you very much for your time

Appendix H: Lessons learnt

In this appendix, lessons learnt from reflections on observations from the present research, previous literature and results from the questionnaires with project team members are combined. These lessons provided the background to the creation of the design process model for low-energy housing, tentatively proposed in section 8.5. Lessons are proposed for 12 of the stages shown in the design process model, as the first two were not covered by the research or any other source. The lessons are presented as a set of bullet points, each credited to the source that informed it. The sources are represented in three ways. The first is the chapter in the present research which informed the point, the second the reference to the publication in which it was suggested. Thirdly 'Questionnaire' is used, followed by initials of project team members from the questionnaires, these initials are explained in the first example of each. These lessons are presented as a summary of those found during the present thesis and could form guidance to help enable members of the construction industry, housing developers and policy makers to deliver low-energy and zero-carbon housing.

3. Formation of team:

- M&E consultants need to have input into the design process at an earlier stage (Questionnaire – A (architect); Questionnaire – QS/PM (quantity surveyor/project manager); Yoklic and Carneval, 2003).
- There needs to be a closer relationship between designers and builders (Questionnaire – A).
- All parties need to be committed from the beginning of the design process (Questionnaire – A; Chapter 5; Chapter 7).
- Engineers need to be involved in the design process from the beginning as they have a significant impact on efficiency (Questionnaire – BSE (building services engineer); Pearl, 2004; Sandahl et al., 1994).
- Good co-ordination is needed between project team members (Questionnaire – QS/PM; Questionnaire – A).

- Negative perceptions about the cost of sustainable approaches need to be addressed (Questionnaire – A; Lowe et al., 2003a).
- The design process needs to be managed effectively in order to deliver low-energy housing (Horsley et al., 2001). This should include: working as a team; maintaining interaction between members; effective communication; team dynamics; and redirecting the team to maintain efficiency (Macmillan et al., 2002).
- The learning process of professionals in the project team needs to be improved, with all parties educated in detail about the standard to be built to as well as issues such as airtightness and thermal bridging (Fortune and Welham, 1995; Lowe et al., 2003a).
- Partnering should be started at the beginning of the project and all parties invited to join (Weingardt, 1996).
- The client needs to be informed about all the environmental design possibilities available (Watson et al., 2000).
- Multi-disciplinary teamwork should be encouraged early on in the design process to create an integrated building (Reed and Gordon, 2000).
- Information on sustainability needs to be distributed to project team members in easy to use formats such as: case studies, rules of thumb, checklists, handbooks and worksheets (Sandahl et al., 1994).
- Appropriate consultants should be selected who will address efficiency and opportunities in other ecological areas (Reed and Gordon, 2000).
- An integrated design team should be used with a different type of architect/client contract; using performance based agreements which give benefits to all parties if costs are reduced or environmental standards improved (Reed and Gordon, 2000).
- The strategy for minimising energy use needs to be tailored to the site characteristics (Long et al., 2006).
- Good working relationships and communication need to be established between project team members (Chapter 5).

- Partnering, transparency and trust need to be embraced by all parties in the project team at the beginning of the design process (Chapter 5; Chapter 7).
- All parties should try and remain open to suggestions by other members in order to achieve a high environmental standard (Chapter 6; Chapter 7).

4. Set/agree principles/standards:

- The project needs to focus on reduction of CO_2 emissions, conservation of energy and waste recycling rather than on costs, programme and density (Questionnaire – A).
- All parties need to agree to and be committed to standards and principles set (Questionnaire – QS/PM; Chapter 5).
- Energy savings gained through reductions in operational energy when calculating embodied energy of a particular construction technique or material need to be considered (Fay et al., 2000).
- Energy performance of the building needs to be considered from the inception of the building (Horsley et al., 2001).
- Previous low-energy projects need to be examined to inform standards set in current projects (Andreu and Oreszczyn, 2004).
- Performance targets need to be set for a range of parameters (Andreu and Oreszczyn, 2004; Pearl, 2004; Reed and Gordon, 2000; Chapter 5) such as percentage energy savings, percentage cost savings, emissions reductions (Long et al., 2006) and airtightness (Action Energy, 2004a).
- Post-occupancy evaluation should be suggested from the beginning of the design process (Andreu and Oreszczyn, 2004).
- Environmental standards need to be set so they are appropriate and realistic for the development, incorporating the principles of the development (Chapter 6).
- Additional information and training should be provided to project team members where necessary (Chapter 6).

- Renewable energy systems should be discussed from the beginning of the design process and realistic targets should be set for their inclusion, which could mean achieving ten to twenty percent of the houses' energy needs and then finding the most effective way to achieve this (Chapter 6).

5. Design brief:

- The design brief needs to refer to: energy performance targets, management expectations, control requirements, information required at each stage and the promotion of feedback (Andreu and Oreszczyn, 2004).
- The design brief needs to set out all problems that need to be solved by the building, including reduction of environmental impact (Watson, 2004).
- The design brief needs to be referred to throughout the design process, as do the principles set for the project (Wallace, 1987).
- The design brief should include developed environmental strategies as well as life-cycle costing and cost-benefit analysis of these strategies (Watson et al., 2000).

6. Outline design:

- Heating and services need to be dealt with together rather than separately (Questionnaire – A; Questionnaire – QS/PM).
- Energy efficiency strategies need to be identified and prioritised (Horsley et al., 2001; Pearl, 2004; Torcellini et al., 2006).
- Life-cycle cost analysis of options needs to be undertaken (Horsley et al., 2001).
- Designs should be tested against agreed targets (Andreu and Oreszczyn, 2004).
- Knowledge from experts and lessons fed forwards from previous projects need to be used (Andreu and Oreszczyn, 2004).
- Principles and standards agreed in stage 4 need to be revisited during outline design to ensure the design incorporates these (Chapter 5).
- Heating and cooling loads should be minimised through daylighting, orientation, envelope performance and fenestration (Pearl, 2004).

- All aspects that can affect the environmental impact of houses at the beginning of this stage need to be discussed as many will need to be designed into the building, such as integrated rainwater recycling, natural ventilation, daylighting (Chapter 6).
- As much cost information as possible needs to be obtained early on in this stage of the design process (Chapter 7).
- More time is needed to design and plan a low-energy project, compared to conventional projects, as more consideration needs to be taken (Chapter 7).

7. Detailed design:

- Those elements that are large consumers of energy need to be tackled by assessing the impact on building performance and life-cycle cost and developing strategies to tackle these (Horsley et al., 2001).
- Feedback should be provided to project team members on options discussed (Horsley et al., 2001).
- Heating and cooling demands should be meet through renewable energy systems and reduced as much as possible through efficient systems (Pearl, 2004).
- Climatic characteristics of the site should be exploited (Torcellini et al., 2006).
- Principles and standard agreed in stage 4 should be revisited (Chapter 5).

8. Final design:

- The decision process should be recorded to inform future projects. Knowledge and experience needs to be shared as this is the most important influence on the decision-making process (Andreu and Oreszczyn, 2004; Mackinder and Marvin, 1982; Torcellini et al., 2006).
- Performance goals need to be checked to see if they have been met (Horsley et al. 2001).
- Making compromises on design specification should be avoided, especially those that will reduce environmental impact. Comparisons that have to be made should be recorded (Andreu and Oreszczyn, 2004).

- Principles and standard agreed in stage 4 should be revisited (Chapter 5).
- Detailed information about systems under consideration should be available to all members of the project team involved in the decision, so that an informed choice can be made (Chapter 6).
- If no renewable energy system can be provided then it needs to be made as easy as possible for buyers of the houses to install systems at a later date (Chapter 6).

9. Specification:

- Condensing boilers should be designed to work on condensing mode for as much as their operation as possible (Action Energy, 2004a).
- An overarching guideline for selecting materials should be considered, such as making sure they are locally sourced and natural (Chapter 6).
- Detailed specifications for particular materials should to be developed and communicated to all members of the project team (Chapter 6).
- Guidance should be used to inform material selection, but alternative materials not covered by such guides as the *Green Guide for Specification* (Anderson et al., 2002) should be considered, especially if they are recycled or re-used (Chapter 6).
- Materials and labour should be sourced as close to the development as possible, to reduce transportation costs and develop the local economy (Chapter 6).
- Alternative thermal insulation materials should be looked at early in the selection process and all cost, performance and all other information needs to be provided. It is useful to be aware that some benefits of using alternative insulation are not easily quantifiable (e.g. health and embodied energy), which is often a difficulty when comparing products (Chapter 6).
- Cost and performance need to be analysed as there will be a point at which extra insulation is not economically viable, as a large increase in thickness gives a very small amount of extra performance (Chapter 6).
- If conventional masonry building techniques are to be used the cavity of the walls should be filled with insulation to achieve the optimum efficiency (Chapter 6).

- Light fitting options that include all low-energy light bulbs should be provided to encourage people to keep the light bulbs provided and not replace them with high energy halogen bulbs (Chapter 6).
- Water consumption should be reduced as much as possible and all easy water saving measures should be taken. Specify low-flush toilets and non-power showers (Chapter 6).
- The specification for the heating and hot water system should be set as early as possible and should be as efficient as possible as it makes a large contribution to energy use in houses (Chapter 6).
- When making decisions like this, detailed information about how the system works, its efficiency and its cost is necessary. This will enable all parties to be adequately consulted to make an informed decision, so that every point of view can be heard and evidence can be presented to make the right decision (Chapter 6).
- Cost of building elements with lower environmental impact needs to be explored as the contractor may have misconceptions about costs (Chapter 6).
- Detailed specifications should be created for all aspects of houses that affect their environmental impact (Chapter 6).
- Alternatives for aspects of the houses should be investigated, with cost, efficiency and other benefits (such as health and embodied energy) presented (Chapter 6).
- Decisions should be, if possible, discussed with members of the project team with expertise in the particular area under investigation (Chapter 6).
- All components of the heating system should be specified to be as efficient as possible (Action Energy, 2004a).

10. Tendering:

- Costs for environmental elements should be investigated as these will reduce the further they are explored (Lowe et al., 2003a).
- Specifications should reflect energy-efficiency concerns (Action Energy, 2004b).

- Local companies should be used in order to reduce the environmental impact of transportation (Chapter 6; Chapter 7).
- Other companies should be approached if the figures returned are not competitive (Chapter 5).
- Items should be tendered directly where possible (Chapter 5).
- Contractors should not be allowed to substitute items with those that have a different specification from that stated (Chapter 5).
- The contractor can add cost premiums due to lack of understanding of environmental features, so ensure that this is avoided by going through cost estimates with the contractor to remove these premiums (Chapter 5; Chapter 6).

11. Contracts:

- Additional drawings and information need to be in the contract to convey design details of sustainable strategies to contractor (Yoklic and Carneval, 2003).
- The contract is important to ensure the environmental standards are included within the construction of the houses (Chapter 5).
- All parties should be involved in the creation of the contract documents (Chapter 5).
- Contractors need to be negotiated with in relation to their overheads, profit margin and incentives given (Chapter 5).

12. Procurement:

- The contractor needs to understand the principles behind the project and make sure buildability is not a problem (Action Energy, 2004b).
- All installed elements must be shown to deliver the targets set (Action Energy, 2004a).
- Principles set at the start of the project need to be adhered to (Chapter 5).
- Value engineering can be used to reduce construction costs, but this can be detrimental to the environmental aspects of the design (Chapter 5).

13. Construction:

- During construction there needs to be a strong site presence by members of the project team who are responsible for implementing the environmental standards to make sure construction is being carried out in an appropriate manner (Roberts et al., 2005).
- The contractor needs to be trained to build to the environmental standard agreed, with attention paid to details (Reed and Gordon, 2000; Chapter 7).
- The impact of design changes on environmental impact should be checked before changes are made during construction (Torcellini et al., 2006).
- Performance indicators should be applied that ensure that the principles of the project are met (Action Energy, 2004b).

14. Handover:

- How the building works needs to be understood, including its faults (Andreu and Oreszczyn, 2004).
- A building logbook should be prepared for users (Andreu and Oreszczyn, 2004).
- Building operators should be educated so they understand how to operate the building in an energy efficient manner (Action Energy, 2004a; Long et al., 2006; Torcellini et al., 2006,).
- Controls and equipment must be commissioned properly (Action Energy, 2004a; Long et al., 2006; Reed and Gordon, 2000).
- Covenants to protect the principles of the development should be considered to stop users increasing the environmental impact of the buildings (Chapter 6).

15. Monitoring and evaluation:

- Performance should be monitored against targets set in stage 4 and feedback to project members for future projects (Action Energy, 2004a; Andreu and Oreszczyn, 2004).
- Make sure the building is maintained properly (Andreu and Oreszczyn, 2004).

- User satisfaction with the building should be established (Andreu and Oreszczyn, 2004).
- Monitoring and feedback are important aspects of the design process (Lowe et al., 2003a).
- Monitoring of the development into occupation is necessary to learn more lessons (Chapter 7).